YELLOW NUTSEDGE (*Cyperus esculentus* L.) INTERFERENCE WITH POLYETHYLENE-MULCHED BELL PEPPER (*Capsicum annuum* L.)

By

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Bell pepper, an economically important vegetable crop in Florida, cannot be grown successfully without controlling yellow nutsedge. Methyl bromide, the only chemical used in polyethylene-mulched bell pepper production that effectively controls nutsedges, is being phased out of production. Information, therefore, is needed for developing alternative yellow nutsedge control measures. Objectives of this research were to determine the number of nutsedge plants tolerated by bell pepper, the time period when yellow nutsedge must be controlled, the distance between nutsedge and bell pepper plants at which pepper yields are reduced, and the activity of 1,3-dichloropropene (1,3-D) + 35% chloropicrin (Pic) and metam-Na on tubers at varying stages of growth. In field experiments, bell pepper and yellow nutsedge plants were grown on polyethylene-mulched, drip-irrigated beds. Respective treatments in the density, critical period, and

distance experiments included initial nutsedge tuber densities (ranging from 10 to 120 tubers$\cdot$m^{-2}), duration of yellow nutsedge interference with pepper and nutsedge-free time (0 to 13 weeks after pepper transplanting), and initial distance between nutsedge plants and a pepper plant (7.6 to 30.5 cm). In the greenhouse experiment, 1,3-D + Pic or metam-Na was applied to dry, imbibed, and sprouted nutsedge tubers. Bell pepper yield losses of greater than 10% were predicted with interference of nutsedge plants from 5 tubers$\cdot$m^{-2}. Nutsedge-free periods of 4 to 5 weeks or 1½ to 6½ weeks after pepper establishment were required in spring and fall, respectively, for not more than 10% loss of marketable pepper fruits. All distances of planted tubers from a pepper plant of 7.6 to 30.5 cm resulted in greater than 10% reductions in pepper fruit yield. In the greenhouse experiment, metam-Na and 1,3-D + Pic effectively controlled yellow nutsedge for 28 days. Tubers imbibed with water before planting were more susceptible to 1,3-D + Pic than tubers planted without prior water imbibition. Near total suppression of nutsedge tubers was needed for a longer period of time in fall than spring to obtain adequate pepper yields. When nutsedge tubers were planted 5 or 10 cm apart, suppression of nutsedge needed to extend to the edge of the 61 cm-wide planting beds. The efficacy of 1,3-D + Pic and metam-Na against yellow nutsedge was enhanced by minimizing volatilization of fumigant gasses, and the efficacy of 1,3-D + Pic enhanced when applied to water-imbibed tubers. Polyethylene-mulched bell pepper exhibited a low tolerance of yellow nutsedge in the plant bed, and acceptable fruit production required the absence of nutsedge from early- through mid-season.

INTRODUCTION

Weed/Crop Competition

Definition and Description of Competition

Effects of undesirable plants on crop plants have been a concern throughout the history of agriculture (Grace and Tilman, 1990). Practices such as pruning, manipulating crop spacing, and weed control have been adapted to maximize the performance of crop plants. Each of these practices changes the proximity and subsequent growth of plants that invariably occur in association with neighbors (i.e., other plants and/or organisms). The interaction among a plant and neighbors is called interference and is further defined as the effect that the presence of a plant has on the growth or development of its neighbors (Radosevich, 1988).

Interference can negatively or positively affect a plant. Negative effects of plant associations include competition, amensalism, and parasitism (Burkholder, 1952). Competition involves mutually adverse effects on each of two associated organisms/plants (Connell, 1990), whereas amensalism and parasitism describe interactions where one of two organisms is not harmed (i.e., a plant that can exude allelopathic substances) or benefits, respectively, by association with the negatively influenced neighbor. Positive effects can occur, for instance, if two species occur in symbiosis with each other. Distinctions among types of interference are important

because it is possible to incorrectly attribute crop yield loss, for example, to competition when, in fact, yield loss may be due to other types of interference such as allelopathy.

Connell (1990) further described competition as "apparent" or "real." Apparent competition was subdivided into two types. The first type involves indirect interaction via a shared enemy (Holt, 1977, 1984). In this interaction, a shared enemy may benefit from an increase in one plant species and subsequently harm a plant of another species. The second type is indirect interaction between two species via another species on the same trophic level. An example of this was described by Volz (1977) where competition between corn and yellow nutsedge was attributed to the positive effect of yellow nutsedge on soil microbes that, in turn, reduced corn yields via denitrification. Real competition, as described by Connell (1990), occurs as one organism causes direct harm to a neighboring organism via physical contact and abrasion or as two or more organisms use a shared resource such as water, nutrients, or light.

Aspects of Resource Competition in Agricultural Settings

Real (resource) vs. apparent competition is often difficult to prove in nature because there are usually a large number of species interacting with each other for an indefinite period of time. In an agricultural setting, however, the number of species interacting in the field and the duration of that interaction are limited to a growing season. Also, the amount of inputs such as water and fertilizer is controlled in agricultural settings.

Two components of resource competition are the effect on and response to resources (Goldberg, 1990). Effect on resources was described as the rate of change in light, water, or nutrient availability in response to increased plant density or biomass. By

studying the effect that plant species grown at varying densities have on resource availability, it is possible to compare the competitiveness of two species by ranking their ability to reduce the amount of available resources. In making interpretations related to resource depletion it is important to distinguish between uptake and nonuptake effects on resources. Uptake effects include physiological activity rates of plants and the ability of plant organs to allocate resources. Nonuptake effects include adding resources (i.e, nutrients and water) and modifying the physical environment.

Resource availability was described as the rate of change in a component of plant fitness (i.e., crop growth and/or yield) in response to increased resource availability (Goldberg, 1990). Competitive plants are those that are able to tolerate low resource availability by maximizing resource uptake, minimizing resource loss, and maximizing efficiency of resource conversion to new growth. It should be noted, however, that tolerance of low resources may not be evidenced by increased yield or growth rates but may instead be manifested by increased survival through means such as dessication tolerance and ability to store resources obtained during temporary periods of abundance. It is also possible that a plant species may be able to tolerate low amounts of one resource but may not grow well at low amounts of another resource.

Climatic conditions, in addition to resources, are also important in understanding interactions among crop species (Radosevich and Holt, 1984). In contrast to resources such as light, water, and nutrients, conditions are not consumed. They include factors such as temperature and photoperiod. Conditions may, in fact, alter the ability of plants to use or tolerate low resource quantities.

Factors that Modify Crop/Weed Interference

In studying crop/weed interference it is important to understand factors that modify interference. These include space, density, and species proportion (Radosevich and Holt, 1984). Space is a conceptual unit consisting of the composite of all resources and interactions needed for plant growth. The concept of "space" allows for the study of how two plants or plant species interact without the need to determine the cause of the interaction. This is because both plants share the same "space," with all its resources; and each plant is a biological indicator of the space utilization of its neighbor. A related concept, spatial pattern, refers to arrangement of and distance between plants on a horizontal plane. Spatial pattern in competition experiments should be defined or controlled to explain or minimize variation within treatments.

Density is the number of individuals per unit of area (Radosevich and Holt, 1984). With increased density, a density is reached where interference occurs among neighboring plants. As density of one species (weed) increases, the performance of neighboring plants of another species (crop) is typically decreased. With further increases in weed density, resources become limited and/or *intraspecific* competition among weeds increases such that *interspecific* competition against the crop is reduced until the rate of loss in crop performance levels off. This relationship between density and performance is known as the *law of constant final yield.*

Species proportion refers to the proportion or ratio of each plant species in a plant stand when there are at least two species within a population of plants (Radosevich and Holt, 1984). The proportion or ratio is also known as relative density. Relative density of

each species in a mixture of species may or may not be of interest in weed-crop competition studies, but it is a factor that may influence weed-crop interaction.

Methods of Studying Competition

Weed scientists are interested in developing threshold levels needed for making informed weed management decisions. It is not adequate to only determine if yields are influenced by the presence or absence of weeds. Additional questions must be answered such as "what is the weed density that causes minimum and maximum yield loss," "when do weeds need to be controlled," and "what is the distance around a crop plant that weeds should be controlled?".

To answer such questions, it is necessary to determine thresholds including the critical density, biological threshold, critical period, and area of influence. The critical density is the weed density that a crop can tolerate without exceeding an economically acceptable level of yield loss. The biological threshold is the weed density above which little or no further yield loss occurs. Although a weed density resulting in the biological threshold may be less than that occurring in a typical field, this parameter is needed to determine the critical period. The critical period is the time period during the growing season when a crop must be kept free of weeds. It relates to when weeds must be controlled. The area of influence is the area over which a weed competes with a target plant.

Appropriate experimental designs to determine these threshold levels include the additive, replacement series, critical period, and neighborhood designs. Choice of experimental design depends on the objectives of the researcher.

Additive designs

An additive design is used to determine the critical density and biological threshold. In an additive design the crop density is held constant while weed density is varied (Cousens 1985; Cousens, 1991; Radosevich 1987; Zimdahl 1980). Because field crop densities are typically constant with varying weed densities, the additive study mimics actual grower conditions. Furthermore, the design allows for evaluation of the effects of full-season weed competition with a crop grown under production practices used by growers.

In designing an additive study, it is important to choose appropriate levels of weed density (Cousens, 1991). Commonly, a geometric series of densities such as 1, 2, 4, 8, 16, and 32 weeds$\cdot m^{-2}$ is used. An arithmetic series such as 1, 3, 5, and 7 weeds$\cdot m^{-2}$ may be used for low weed densities when yield response is expected to be linear. In either case, the densities chosen should include those resulting in minimal and maximal yield losses; and it is desirable to have the greatest concentration of points on the steepest part of the curve.

With results from an additive study it is possible to plot, via regression analysis, the effect of increasing weed density on crop yield loss. According to Cousens (1991), hyperbolic models usually provide a better fit than quadratic, square root, or sigmoidal models. Choice of a model should depend not only on the coefficient of determination (r^2) value but also on biological properties. For example, a quadratic equation may give a high value for r^2 but may force an unacceptable maximum on data that is asymptotic. Once the data are fitted to a model, the resulting equation may be used to estimate, within the constraints of the design, parameter values and yield loss at any density.

Replacement series design

Unlike an additive design, a substitutive approach known as the replacement series design allows for the separation of total (crop + weed) density and proportion of the crop and weed in plant stands. In the replacement series design, proportions of two species (i.e., crop and weed) are varied while the total density remains constant (Cousens, 1991). As it is difficult to vary crop density in the field, most replacement series studies are conducted in the greenhouse. Monocultural stands of each species are also included as treatments (Radosevich, 1987). Although proportions are used in the design, the purpose of the design is not to study the effect of proportion per se (Cousens, 1991; Radosevich, 1987) but to determine which of two species is the stronger competitor and to learn how the two species interact. In accomplishing these objectives, derived rather than direct variables are used.

To determine which species is the most competitive, relative yields in mixtures are used. Relative yield for each species at each proportion is calculated by dividing the yield with each proportion by the mean monocultural yield (Roush et al., 1989). Relative yield for each species may then be plotted against proportion. The equivalent yield ratio is the proportion at which the resulting lines for relative yield intersect. From the equivalent yield ratio it is possible to determine which species is the most competitive. If, for example, the equivalent yield ratio was obtained with a weed:crop proportion of 25:75, the conclusion would be that one weed could produce as much yield as three crop plants, indicating that the weed is more competitive than the crop.

Relative yield total may also be plotted against proportion by summing the relative yield for each species at each proportion. Relative yield total is useful for

comparing the performance of two species in mixtures vs. that with monocultures. For instance, if relative yield total does not change over proportions it may be concluded that the yield produced by both species in mixtures is equal to that expected with each species grown separately.

Relative yield and relative yield total can also be used to learn something about how the weed and crop interact. Several outcomes are possible (Radosevich, 1987). First, it may appear that the weed and crop are planted so far apart that they do not interact; however, it is possible that, in fact, the weed and crop compete equally (i.e., equivalent weed:crop yield ratio of 50:50) with the contribution to total yield by each species in direct proportion to its presence in the mixtures. Secondly, it may be that one species is more aggressive than the other and contributes more than the other to the total yield, indicating that competition is for a common resource(s). A third possible outcome is mutual antagonism where both species contribute less than expected to the total yield and combined yield of both species is less when grown in mixtures than when either species is grown in pure stands. A fourth possibility is mutual benefit, where the yield with species grown in mixture exceeds that with pure stands.

With a replacement series design incorporating density in addition to proportion it is also possible to evaluate the relative effects of intra- and interspecific interference of each species (Radosevich, 1987; Radosevich, 1988) using a variable called reciprocal yield. A separate line is drawn for each species by plotting reciprocal yield against density using a linear equation. The result is a set of more or less parallel lines. The degree of separation between the lines shows the extent of intraspecific competition while

the slope of the lines shows the extent of interspecific competition. A flat or steeply sloped line shows a weak and strong interspecific competitor, respectively.

A requirement for proper design of a replacement series experiment is a total density that is sufficiently high to obtain constant final yield (Cousens, 1991). If a replacement series study is conducted with a density less than that resulting in constant final yield, then interpretation of proportion effects may be influenced by the total density used. It is possible to conduct replacement series studies with multiple total densities to obtain information on potential density effects.

Critical period studies

To determine the critical weed-free period necessary to produce acceptable crop yields, a weed removal and plant back study is conducted (Oliver, 1988) within a single experiment or as separate experiments. These experiments are conducted using multiple or single weed densities. If using a single density, the density should be that which results in the biological threshold obtained with an additive study. The critical period may be underestimated if the weed density used is too low (i.e., below the biological threshold).

In a weed removal experiment, naturally occurring or planted weeds at crop planting are removed at predetermined times during the growing season. A season-long weed-free (weeds never established) and weedy (weeds never removed) check should be included in the design. After weeds are removed, the crop is kept free of weeds for the remainder of the season. Results obtained with a weed removal experiment show how long a weed, present at crop planting, may be allowed to compete with the crop before yields are reduced.

In a weed plant back experiment, weeds are allowed to emerge with the crop or weeds are planted at predetermined times during a growing season. To obtain a desired density, natural populations are either thinned or weeds are planted at the chosen density. As with the removal experiment, a weed-free (weeds never established) and season-long competition (weeds established at the same time as the crop) check should be included in the design. Once the weeds are established they are allowed to grow and compete with the crop for the duration of the season. Results from plant back experiments show how long a crop must be kept weed-free to obtain satisfactory yields.

Within each replication (four to six are preferred), data such as crop yield obtained with each weed removal or planting treatment may be converted to percent of that obtained with a weed-free treatment (Oliver, 1988). These data can then be plotted as a function of weed plant back or removal time on one graph to determine the critical weed-free period. For example, if weed removal study data show that weeds may be allowed to compete for 3 weeks and weed plant back study data show that a crop must be kept weed-free for 5 weeks, then the critical period is between 3 and 5 weeks. From the graph, a critical period can be identified for any level of yield loss.

Neighborhood studies

A neighborhood design is useful when the nearness of a weed species to a target crop plant is of primary interest (Oliver, 1988; Radosevich, 1987). The two main factors influencing performance of the target plant are distance between the crop and weed and density of the weed species. The primary objective of these studies is to determine the distance from a crop plant at which weed control is necessary.

In a typical neighborhood study, individual weeds are spaced 2 to 3 m apart within a crop row, far enough to prevent intraspecific competition among weeds (Oliver, 1988). Crop plants placed on either side of the weed plants are harvested several times during the season, and weeds are harvested. At each harvest date, crop plants growing within several row segments (for example, 0 to 12.5, 12.5 to 25, and 25 to 50 cm from the crop plant) on both sides of the weed are cut at the soil surface. At each distance, samples collected from all sides of the weed are combined to represent circles with varying diameters around each weed.

There are variations of the experiment described by Oliver (1988). Goldberg and Werner (1983) described a study in which the crop species is evaluated over a range of weed densities, and the crop species is grown alone or is surrounded by individuals of the weed species. The spatial arrangement of crop and weed species can also be varied.

Several equations have been used to describe the performance of the crop plant as influenced by proximity to the weed species. Mack and Harper (1977) expressed plant mass of plants in sand dunes as a log-linear function of factors including mass and distance of neighbors. Goldber and Werner (1983) estimated performance (i.e., growth rate, survival, or reproductive output) of a crop plant as a function of the "amount of neighbors" (i.e., density, biomass, or leaf area). A variation of their equation included a distance factor to account for diminishing effects of increasingly distant neighbors. Weiner (1982) constructed a model in which seed yield of annual plants was a function of the number and species of individual neighbors within each of several concentric neighborhoods.

Yellow Nutsedge (*Cyperus esculentus* L.) Biology

Distinguishing Characteristics

The two *Cyperus* species of major agricultural importance are purple (*Cyperus rotundus* L.) and yellow (*C. esculentus* L.) nutsedge. Both are perennials and are considered among the world's worst weeds (Holm et al., 1977). Yellow nutsedge is found in all U.S. states, whereas purple nutsedge is most commonly found in the southern U.S. (U.S. Dept. Agric. Res. Serv., 1970). The two species commonly occur in mixed stands and are difficult to distinguish until flowers appear. In mixed stands, purple nutsedge can be differentiated from yellow by a reddish- or purplish- brown inflorescence, leaves with boat-shaped leaf tips, and scaly rhizomes producing tubers and bulbs in chains (Wills, 1987). By comparison, yellow nutsedge has a yellowish-brown or straw-colored inflorescence, leaves with long, tapered tips, and weak rhizomes that usually terminate in bulbs or single tubers. Typically, yellow nutsedge thrives in low, moist areas, and purple nutsedge is found on well-drained soils (Holm et al., 1977).

Origins and Taxonomy

Nutsedge species are widespread in tropical and temperate zones around the globe. The ancient, edible chufa is of Mediterranean origin (de Vries, 1991). Yellow nutsedge, coded as CYPES in the Weed Science Society of America Composite list of weeds, is classified by taxonomists into the class Angiospermae, the subclass Monocotyledonae, order Graminales, and the family *Cyperaceae* (sedge family) (Gleason, 1963). Gleason (1963) reported approximately 75 genera and over 4000 species within the *Cyperaceae* family.

Kukenthal (1936) described eight botanical varieties of *C. esculentus*, but only four (*esculentus, leptostachyus, macrostachyus, and hermanii*) were subsequently recognized by Schippers et al. (1995) after testing characteristics of material collected from herbariums from each continent. These varieties were called "weedy" by de Vries (1991) and were distinguished from the cultivated variety, *sativus*, referred to as "Chufa." Both weedy nutsedge and Chufa are included in *C. esculentus* according to Linnaeus (1753). De Vries (1991) concluded that the similarity and history of Chufa and weedy yellow nutsedges did not provide a taxonomical basis for separating the two groups, but proposed that Chufa be named as a cultivar of yellow nutsedge (*Cyperus esculentus* L. cv. Chufa) with the following criteria: yellow or greyed orange tubers, RHS Color Chart numbers 163-167; tubers 0.5 cm to 3 cm long, borne on short rhizomes; rarely flowering; sensitive to frost; and shoots ascending.

Propagation and Life Cycle

Yellow nutsedge can produce large numbers of seed as shown by Hill et al. (1963) who, in Massachusetts, reported 605 million seeds$\cdot$ha^{-1}. Viability of yellow nutsedge seed varies. Justice and Whitehead (1946), for example, found that the viability of mature seed ranged from less than 5% to greater than 40%. Factors influencing seed viability include temperature, light, and moisture. Adequate soil moisture was critical for seed germination in experiments by Lapham and Drennan (1990). Although growers of irrigated cotton in California believed seed to be the main means of yellow nutsedge dissemination (Thullen and Keeley, 1979), propagation of yellow nutsedge by seed is not considered of major importance in cultivated fields (Mulligan and Junkins, 1975; Stoller,

1975; Stoller and Sweet 1987) due to lack of seedling vigor and absence of ideal conditions for germination.

The primary source of yellow nutsedge establishment is underground tubers. Most (99%) of the tubers in a peat soil were located at a soil depth of less than 25 cm in a report by Tumbelson and Kommedahl (1961). Mature tubers are tan to brown colored and spherical in shape (Stoller et al., 1972). A basal and distal end may be discerned with the basal more rounded than the distal end.

Tubers lie dormant in the soil until stimulated to sprout. In temperate climates, soil warming is the primary sprouting stimulus (Stoller, 1981). In addition to temperature, mechanical disturbance has an effect on tuber dormancy. Taylorson (1967) observed that both mowing and disk harrow cultivation sharply increased sprouting of yellow nutsedge tubers during a period when tuber sprouting in an undisturbed stand was low. Disk harrow cultivation increased sprouting more than mowing.

Tuber germination was not influenced by tuber sizes ranging from 61 to 294 $mg \cdot tuber^{-1}$; however, dry weight of seedlings collected 16 days after planting tubers 5.3 cm deep in paper cups in a greenhouse at 22 to 30°C was correlated at $P \leq 0.01$ ($r = 0.57$) with planted tuber dry weight in a study by Stoller et al. (1972). Thus, tuber germination and size were not related but yellow nutsedge plant vigor was a function of tuber size.

Upon breaking of dormancy and subsequent germination, rhizome(s) emerge from the distal end of yellow nutsedge tubers (Jansen, 1971). Nodes, internodes, and cladophylls are clearly visible on rhizomes. Upon exposure of a rhizome to light and diurnal temperature fluctuations at the soil surface, basal bulbs are formed (Stoller et al., 1972) 1 to 2 cm from where the rhizome tip first encounters light. Roots form and radiate

horizontally from the rhizome in the area near the basal bulb. Basal bulbs contain meristematic tissue for the formation of roots, secondary rhizomes, leaves, and the flower stalk (Stoller and Sweet, 1987).

Several weeks after a primary shoot (rhizome tip) emerges, secondary rhizomes are produced from the basal bulb (Stoller and Sweet, 1987). These rhizomes turn upward and form new basal bulbs that, in turn, form additional shoots and rhizomes resulting in rapid vegetative proliferation of shoots. This vegetative phase is favored by long days of 14 to 16 h (Jansen, 1971). New tubers may also be formed from secondary rhizomes 4 to 6 weeks after shoot emergence (Stoller and Sweet, 1987). Growth of nutsedge shoots and rhizomes remains active until the middle of August (Jansen, 1971). Then, as daylength decreases to less than 14 h, reproductive processes of flowering and tuber formation are initiated (Jansen, 1971; Williams, 1982).

Numerous tubers and shoots can result from the sprouting and growth of a single tuber. Tumbelson and Kommedahl (1961) found that one yellow nutsedge tuber in the field produced 602 plants$\cdot$m^{-2} and 2184 tubers$\cdot$m^{-2} in 16 weeks. In spring 1999 in Florida, Locascio and Dickson (2000) observed an increase in nutsedge (mixture of yellow and purple) density from 181 to 950 plants$\cdot$m^{-2} between 11 May and 22 June. Multiple shoots per tuber and the ability of a tuber to sprout more than once contribute to high nutsedge plant densities. Tumbleson and Kommedahl (1961) reported that, in petri plates, each tuber produced zero to seven shoots, with an average of two. Stoller et al. (1972) found that 52.2% and 26.5% of tubers sprouted two and three times, respectively.

Control of tubers is difficult due to tuber dormancy resulting in variable sprouting times. Thullen and Keeley (1975) found that, in 2 to 4 weeks, 75% to 80% of yellow

nutsedge tubers sprouted with 40% of these producing more than one shoot. Some of the unsprouted 20% to 25% of the tubers sprouted the following month, and sprouting continued until all tubers either sprouted or died. One tuber in their experiment sprouted for the first time 64 weeks after the first planting. They observed a high degree of variability in sprouting characteristics such as multiple sprouting, sprouting interval, and sprout weight.

Nutsedge Interference With Vegetables

Yield Losses Due to Nutsedge Interference

Yellow and purple nutsedge infestations, when not controlled, have resulted in significant crop yield losses. Bell pepper fruit yield losses of 73% (Morales-Payan et al., 1998) and 32% (Morales-Payan et al., 1997) have been reported in greenhouse studies. Significant yield losses for other vegetables have also been reported. Watermelon fruit yields were reduced by up to 98% by yellow nutsedge (Buker III et al., 1998). William and Warren (1975) reported field grown crop losses due to full-season purple nutsedge competition as follows: garlic 89%; okra 62%; two carrot cultivars, 'Kuroda' and 'Nantes' 39% and 50%, respectively; green bean 41%; cucumber 43%; cabbage 35%; and tomato 53%. Purple nutsedge densities of 75 plants$\cdot$m^{-2} reduced radish yields by 100% (Santos et al., 1998).

Thresholds Determined

Critical nutsedge densities and densities resulting in the biological threshold have been reported for several vegetable crops. In a greenhouse study by Morales-Payan et al. (1997), the critical purple nutsedge density for 10% bell pepper fruit yield loss was obtained with an initial density of 50 tubers$\cdot$m^{-2}. In this study, pepper fruit yield loss

increased linearly to 32% as initial tuber density increased from 0 to 200 tubers·m^{-2}. In another study, yield loss increased linearly to 73% with increased initial tuber density from 0 to 300 tubers·m^{-2} (Morales-Payan et al., 1998). The critical density for 10% tomato fruit yield loss and the density resulting in the biological threshold was 12.5 and 50 planted tubers·m^{-2}, respectively, in work by Morales-Payan (1999). Marketable tomato fruit yield loss with 50 to 200 tubers·m^{-2} was 45% compared to 65% loss for medium size fruit. The critical density for 10% watermelon fruit yield loss was obtained with 25 and 37 planted yellow nutsedge tubers·m^{-2} in spring and fall, respectively, as reported by Buker III et al. (1998).

The critical nutsedge-free period has been determined for several vegetable crops. William and Warren (1975) reported a critical purple nutsedge free period for several vegetable crops grown on irrigated sandy clay to clay soils in Brazil. This period was between 3 and 13 weeks for garlic; 3 and 7 weeks for okra, cucumber, and 'Nantes' carrot; 3 and 5 weeks for tomato and 'Kuroda' carrot, and at 4 weeks for cabbage and green bean. Their results showed that the critical nutsedge-free period for most crops is during the first third of the growing cycle before the reproductive stage of the crop begins. Their results also showed that crops such as garlic that did not produce a significant amount of leaf canopy required a longer nutsedge-free period than for more competitive crops such as tomato.

A replacement series study of yellow nutsedge interference with greenhouse-grown tomato by Santos et al. (1997) showed that yellow nutsedge competed more strongly with itself than with tomato. The dry weight of one tomato shoot equaled the dry weight of three yellow nutsedge plants, indicating that tomato was a stronger competitor

than yellow nutsedge. Yellow nutsedge, however, competed more strongly than purple nutsedge with tomato.

Means of Nutsedge Interference

Nutsedge interferes with crops such as bell pepper via competition for resources including light, nutrients, and water. Of these three resources, light is often the most important for vegetables supplied with nutrients and water via fertigation. William and Warren (1975) concluded that purple nutsedge competed for light in slow growing vegetable crops such as garlic that did not produce a large leaf canopy. Research by Ponce et al. (1996) showed that bell pepper was sensitive to shading by weeds. They found that bell pepper height and yield reduction increased with earliness of black nightshade (*Solanum nigrum*) emergence. Bell pepper fruit yield was reduced 93% with black nightshade emerging simultaneously with the pepper crop.

Yellow nutsedge competition with field-grown tomato for nutrients was observed by Morales-Payan (1999). In this work, N, P, and K accumulation in yellow nutsedge shoots increased while N, P, and K content in tomato leaves decreased with nutsedge density. The rate of nutrient sequestration with increased nutsedge density was more rapid with initial weed densities between 25 and 50 than between 100 and 200 plants$\cdot$m^{-2}. With 200 plants$\cdot$m^{-2}, N, P, and K uptake by nutsedge shoots was 153, 103, and 159 kg$\cdot$ha^{-1}, respectively.

Nutsedge interference with crops has also been attributed to allelopathic substances (Drost and Doll, 1978; Drost and Doll, 1980; Gilreath, 1981; Meena and Varshney, 1998; Sanchez et al, 1973). Most of the work has been done with agronomic crops. For instance, Drost and Doll (1980) reported that yellow nutsedge tuber extracts

reduced corn (*Zea mays*) and soybean (*Glycine max*) dry weight more than leaf extracts. Sanchez et al. (1973) found that yellow nutsedge extracts were phenolic in nature. Quayyum et al. (2000) reported that the major compounds extracted from purple nutsedge leaves and tubers via ethyl acetate followed by gas chromatography-mas spectroscopy were dicarboxylic, phenolic, and fatty acids. Gilreath (1981) found that leachates from purple nutsedge plants and tubers reduced the growth of cucumber (*Cucumis sativus* L.), lettuce (*Lactuca sativa* L.), and tomato plants. Similarly, Kawisi et al. (1995) found that purple nutsedge tuber extracts reduced the growth of squash (*Cucurbita pepo* cv. Felix) roots by 95% to 99%.

Nutsedge interaction with bell pepper was influenced by crop production practices in a study by Morales-Payan et al. (1998). With 70 $kg \cdot ha^{-1}$ of N applied to greenhouse-grown bell pepper, fruit yield loss was not influenced by initial purple nutsedge densities of 0, 100, 200, and 300 $plants \cdot m^{-2}$. Increasing the N supply from 70 to 210 $kg \cdot ha^{-1}$ did not reduce yield losses due to purple nutsedge competition. Use of seed vs. transplants was also shown to influence weed interference effects on tomato. A minimum of one weed control operation (fields were infested with weeds other than nutsedge) was necessary to prevent yield loss of transplanted 'Springset' tomatoes compared to two weed control operations when tomatoes were seeded into the field (Weaver and Tan, 1983; Weaver and Tan, 1987).

Production practices such as crop spacing and row arrangement (Batal and Smittle, 1981; Everett and Subramanya, 1983; Locascio and Stall, 1982; Locascio and Stall, 1994; Stofella and Bryan, 1988), fertilizer rate (Everett and Subramanya, 1983; Hartz et al., 1993; Locascio and Stall, 1982; Locascio and Stall, 1994) and method of

application (Batal and Smittle, 1981; Csizinsky, 1994; Hartz and Hochmuth, 1996; Locascio et al., 1981), mulching (Locascio and Currey, 1973), transplanting depth (Vavrina et al., 1994), and water management (Batal and Smittle, 1981; Hartz and Hochmuth, 1996) have been studied to provide information needed to optimize bell pepper crop vigor and resulting fruit yield. Crop vigor, as influenced by these practices, is related to crop competitiveness against weeds.

Methods of Nutsedge Control

Bell pepper is a major Florida vegetable crop with over 7,400 ha planted annually between 1984 and 1999 (Witzig and Pugh, 2000). In 1998-1999, the value of bell peppers ($243 million) produced in the state ranked second to tomato with 15.4 % of the total value of Florida vegetables. Considering the importance of bell pepper and high crop yield losses associated with nutsedge infestations, nutsedge control is imperative.

Since the 1970's, methyl bromide has been the primary means of nutsedge control in vegetable fields due to its consistent control of soil pests under a wide range of growing conditions, low cost, and ease of use (Bewick, 1989; Overman and Martin, 1978; Williamson et al., 1955). Due to its alleged contribution to the depletion of the stratospheric ozone layer, methyl bromide is being phased out of production in the United States (Environmental Protection Agency, 1999; Watson et al., 1992). Therefore, it is necessary to develop alternative control strategies. Methyl bromide alternatives discussed below include chemical and biological control, cultural methods, and solarization. These may be used alone or in combination as an integrated approach to weed management (Walker and Buchanan, 1982).

Chemical Control

Most of the methyl bromide alternative research has been focused on chemical alternatives. These alternatives include other fumigants, herbicides, and fumigant-herbicide combinations. As there are few new products being released, most chemical alternatives being studied are old products.

The leading methyl bromide alternative for polyethylene-mulched tomato production is 1,3 dichloropropene (1,3-D) + chloropicrin (Pic) combined with pebulate (Locascio et al., 1997). Chloropicrin is very effective against soil-borne diseases and 1,3-D is an effective nematicide. Applied in combination, 1,3-D and Pic provided soil disease and nematode control but lacked activity against purple and yellow nutsedge (Gilreath et al, 1994; Stall, 1994). Hence, it was necessary to also apply a herbicide, pebulate. This combination improved nutsedge control compared to that with 1,3-D + Pic alone (Gilreath et al., 1996) and has provided a similar degree of pest control as methyl bromide (Gilreath et al., 1994; Locascio et al., 1997). Locascio et al. (1997) reported that pebulate (at 4.5 $kg \cdot ha^{-1}$) combined with 1,3-D + 17% Pic (at 327 $L \cdot ha^{-1}$) produced field-grown tomato yields that were 85% to 100% of those obtained with methyl bromide.

There are several problems in using 1,3-D. The label requires that applicators wear suits made of tyvek, a full face respirator, and rubber gloves and boots. This gear is expensive and uncomfortable. Another problem is a three-week delay between application and crop planting. Because of these disadvantages and others, work has been done to investigate the efficacy of pebulate combinations that do not include 1,3-D. Results have been inconsistent. In a study by Gilreath et al. (1995) control of purple nutsedge with pebulate combined with Pic, dazomet, or metam-Na was equal to that

obtained with methyl bromide. Olson et al. (1996), on the other hand, found that metam-Na plus pebulate did not reduce yellow and purple nutsedge infestations compared to those found in untreated plots. In a study by Locascio et al. (1995), metam-Na plus pebulate reduced nutsedge numbers below those present in untreated plots, but numbers were not as low as with methyl bromide.

Due to problems with the use of in-row applied 1,3-D, work has also been conducted with broadcast applications of 1,3-D + Pic. With broadcast applications, bedding and mulch application can be done several days after the chemical is broadcast applied by injection to about 25 cm, thereby precluding the need for protective clothing for a large number of workers. Broadcast applications of pebulate combined with 1,3-D + 17% and 35% Pic rototilled to a 25 cm depth in a 1.8 m area, however, did not improve nutsedge control relative to that obtained with in-row applications (Locascio and Dickson, 2000).

For pepper production, there is no methyl bromide alternative that consistently controls weeds. Pebulate has provided some nutsedge control when applied with soil fumigants but is not registered for use on pepper. In one experiment, 3.4 $kg \cdot ha^{-1}$ pebulate reduced pepper plant vigor by 15% (Bagley and Beste, 1982). Stall and Gilreath (1996), however, found that pepper was tolerant of up to 4.5 $kg \cdot ha^{-1}$ pebulate. Napropamide is the only herbicide with nutsedge activity labeled for use on pepper, and control of nutsedge with this material is erratic (Pritts and Kelly, 2001). In polyethylene-mulched fields, napropamide must be applied preplant on the bed surface, and there is no post-emergence herbicide that may be applied that controls nutsedge in pepper.

The phaseout of methyl bromide and the lack of herbicides with acceptable nutsedge activity is likely to increase reliance on dazomet, 1,3-D + Pic, and metam-Na. Dazomet and 1,3-D + Pic have shown little activity against nutsedge in tomato production (Locascio et al., 1997). Mixed results have been obtained with metam-Na alone or in combination with 1,3-D + Pic.. Csinos et al. (2000) showed that metam-Na (468 $L{\cdot}ha^{-1}$) + 1,3-D with 17 % Pic (126 $L{\cdot}ha^{-1}$) provided good control of most pests when covered with polyethylene film immediately after treatment. In contrast, Jaworski et al. (1980) and Locascio et al. (1997) found that metam-Na was less effective than methyl bromide in terms of nutsedge control in pepper transplant and tomato production fields, respectively. Erratic performance of metam-Na may be due to fumigant loss by volatilization (Goldwasser et al., 1994; Klefield et al., 1991) and variable temperatures at time of application (Ben-Yephet and Frank, 1985), fumigant rates (Stall, 1994), and differences in soil distribution of the chemical as influenced by soil texture (Ben-Yephet and Frank, 1989; Gerstl et al., 1977).

Another potential strategy for nutsedge control in pepper is repeated stimulation of tuber sprouting (i.e., by practices such as irrigation and tillage) and herbicide applications to emerged nutsedge shoots prior to crop establishment. This strategy is based on the observation that nutsedge carbohydrates are lost with multiple sproutings. Stoller et al. (1972) reported that tubers germinating three successive times lost 60% of their initial dry weight and content of carbohydrates, oil, starch, and protein during the first germination. This approach has shown promise in work with glyphosate (Cools and Locascio, 1977; Fraedrich et al., 2002), a broad-spectrum, systemic herbicide that is readily translocated throughout a plant after foliar application and absorption (Doll and

Piedrahita, 1978; Chase and Appleby, 1979a; Pereira, and Crabtree, 1986). It has activity against nutsedge (Cools and Locascio, 1977; Chase and Appleby, 1979b; Doll and Piedrahita, 1982), especially when tubers are nondormant and when complete coverage of actively growing, young shoots is obtained (Fraedrich et al., 2002; Zandstra and Nishimoto, 1977; Doll and Piedrahita, 1978).

Cools and Locascio (1977) obtained better purple nutsedge control in the summer and fall than during the spring, and excellent control (up to 98%) was obtained only with applications made in two or three consecutive seasons. Tuber dormancy, due to low temperatures, reduced the efficacy of glyphosate in the spring, but two spring-season applications one week apart provided better control than one. Fraedrich et al. (2002) applied glyphosate to fields infested with purple nutsedge up to three times in 1999 and two additional times in 2000. Over this two year period, the number of viable tubers declined by 98% from 516 to 11 tubers$\cdot$m^{-2}. They found that soil moisture and nutsedge plant size at application time influenced the efficacy of glyphosate. The influence of soil moisture on glyphosate performance was also shown by Mosssavi and Dore (1979) who found that glyphosate activity on purple nutsedge was reduced when applied to drought stressed plants compared to that obtained when applied to plants grown with soil moisture at field capacity.

Biological Control

Biological control of weeds is accomplished with natural enemies. Classical biological control is the introduction of nonindigenous natural enemies (Phatak et al, 1987) whereas inundative biological control is the timely augmentation of an indigenous natural enemy resulting in high inoculum pressures and subsequent suppression or death

of the weed host (Phatak et al., 1987). Phatak et al. (1987) listed 132 insects that have been associated with purple and/or yellow nutsedge. About half of these were known to feed on crop plants, and four of the insects have been studied in detail. These include three moths (*Bactra verutana* Zeller in the United States, *B. minima* Meyrick and *B. venosana* Zeller in the Indian subcontinent) and a weevil (*Athesapeuta cyperi* Marshall in southeast Asia). Attempts using the classical strategy to control purple nutsedge at several locations, however, were unsuccessful as evidenced by lack of subsequent recovery and/or high parasitism of the biological control agents. Using an inundative approach, Frick and Chandler (1978) reduced aboveground growth of purple nutsedge by 30% to 60% within four to seven weeks after the last release of *B. verutana*.

A fungal bioherbicide agent, *Dactylaria higginsii*, was reported to be pathogenic to greenhouse-grown purple and yellow nutsedge (Kadir and Charudattan, 2000). Nutsedge shoot and tuber dry weights were reduced 73% and 67%, respectively, after inoculation with conidial suspensions of *D. higginsii*. A rust organizm, *Puccinia canaliculata*, applied alone or in combination with herbicide(s) has also been evaluated (Beste et al., 1992; Callaway et al., 1986) for nutsedge control. Combination treatments of pebulate followed by rust inoculation, however, were not effective against yellow nutsedge in tomato fields (Beste et al., 1992).

Research has also showed that yellow nutsedge is inhibited by allelopathic effects of sweet potato (*Ipomoea batatas*). Harrison and Peterson (1994) found that yellow nutsedge was highly sensitive to compounds in the periderm of sweet potato cv. Regal. In an earlier experiment (Harrison and Peterson, 1991), they found that yellow nutsedge did not greatly affect sweet potato growth, but yellow nutsedge shoot dry weights of

plants grown with sweet potato were less than 10% of those obtained in the absence of sweet potato.

There are several reasons for inconsistent weed control with biological control agents. First, control is generally achieved slowly and may not occur in time to prevent the competitive effects of weeds. Secondly, establishment of the bioherbicide agent is difficult to obtain if conditions needed for fungal growth do not exist during the crop growing season. Finally, bioherbicide agent survival in the field may be reduced by fungicides and insecticides applied to vegetable crops.

Cultural Methods

Cultural practices that may be manipulated to control weeds include cultivation, crop rotation, use of cover crops, and mulching. Preplant tillage brings nutsedge tubers to the surface where they are subject to dessication and/or cold injury (Stoller and Wax, 1973; Wax, 1975). Three cultivations at monthly intervals reduced the number of newly formed yellow nutsedge tubers in the field (McCue and Sweet, 1982). Preplant tillage can also be used in conjunction with herbicides or soil fumigants as cultivation has been shown to stimulate tuber sprouting (McCue and Sweet, 1982), rendering them susceptible to chemical control. A disadvantage of cultivation is that nutsedge tubers can be spread by tillage equipment.

Crop rotation and use of cover crops was used for many years, prior to the time when methyl bromide was widely used, to control weeds. Yellow and purple nutsedges are sensitive to shading from crops that produce a canopy early in the season (Dawson, 1964; Keeley and Thullen, 1978; Khan and Mahmood, 1991; Morales-Payan et al., 1997; Patterson, 1982; Walker and Buchanan, 1982). Therefore, choice of crops in a rotation,

as well as cover crops, should be made based on the ability of crops to produce a canopy early in the season that shades out nutsedge. Although crop rotation incorporating cover crops has been an important tool for weed management in the past, reliance on soil fumigants and synthetic fertilizers coupled with reduced land area available for vegetable production has reduced the use of crop rotation in recent years.

Flooding the soil prior to crop planting to control nutsedge has also been studied. Nutsedge control, however, was poor because dormant tubers were able to sprout after the flooding period had ended (Nelson et al., 1999). Problems with soil flooding include the need for large quantities of water, mosquito control, and impact on neighboring crops.

Mulching with materials such as polyethylene controls weeds by excluding light. This method, though, does not control nutsedge due to the ability of rhizome tips to penetrate commonly used polyethylene films. (Locascio and Currey, 1973; William, 1976).

Solarization

Soil solarization is a practice used to control weeds and diseases with high temperatures induced by covering planting beds, about eight weeks prior to crop planting, with clear, polyethylene film. After solarization, the polyethylene must be painted to exclude light, thereby limiting potential growth of dormant weed seeds. Painting of the mulch (black in spring; white in fall) is also necessary to prevent crop injury during periods of high soil temperatures.

Effectiveness of soil solarization is dependent on obtaining sufficiently high soil temperature to control/kill weeds. Chase et al. (1999) obtained 100% nutsedge tuber mortality using diurnal soil temperature oscillations with maximum temperatures of 50

and 56°C and a minimum temperature of 26°C. They also found that 6 weeks of solarization with thermal-infrared-retentive (TIR) films resulted in higher temperatures and a higher level of purple nutsedge control than with a 30-μm low density polyethylene (LDPE) clear film. Residual nutsedge control was 95% and 92% with 75- and 100-μm TIR film, respectively. Stevens et al. (1999), found that a TIR film increased the soil temperature at 5 cm depth by 5°C compared to that obtained with conventional LDPE film.

Chase et al. (1999) also found that, with TIR films, more emerged purple nutsedge plants were killed by foliar scorching than with the LDPE film. Foliar scorching under clear films occurs due to the failure of nutsedge rhizome tips to penetrate the mulch (Chase et al., 1998 and Patterson, 1998). Chase et al. (1998) attributed the lack of rhizome tip penetration through clear mulch to a light-dependent morphological change in rhizome tips causing the sharply pointed scale leaves surrounding the meristem to unfurl.

Foliar scorching is an important method of nutsedge control with solarization as it is difficult to obtain temperatures lethal to tubers occurring below 10 to 12.5 cm (Albregts et al., 1996; Chase et al., 1999).

Solarization alone or in combination with herbicides works best in hot, arid climate such as that in Israel. In Florida, results have been mixed. In some instances, solarization has been found to be effective for tomato (Overman, 1985; Overman and Jones 1986) and strawberry (Overman et al., 1987). Gilreath et al. (1999) found that fall-grown tomato yields with solarization were less than those obtained with methyl bromide. In their study, solarization provided a degree of purple nutsedge control similar to that with methyl bromide, but crabgrass [*Digitaria ciliaris* (Retz.) Koel.] and root knot

nematode (*Meloidogyne* spp.) control was less with solarization than methyl bromide. Strawberry yields with solarization (21 Aug. to 9 Oct.) alone were much lower than yields with methyl bromide-chloropicrin due to a low number of days with soil temperatures ≥50 °C (Locascio et al., 1999).

Inconsistent performance and lack of widespread grower acceptance of solarization in Florida is due to several factors. Frequent cloud cover/rain and subsurface irrigation result in reduced soil temperatures and effectiveness of solarization. Also, the polyethylene film must be laid down about two months before planting. Therefore, solarization is most feasible as a fall production practice in a state where most vegetables are grown during the spring season.

CHAPTER 1
INTERFERENCE OF YELLOW NUTSEDGE WITH BELL PEPPER AS INFLUENCED BY INITIAL YELLOW NUTSEDGE PLANT DENSITY

Introduction

Reduction of crop yields by weed interference is a function of weed density. An additive design is suited for studying the effect of weed density on crop/weed interaction. In an additive design, crop density is held constant while weed density is varied (Cousens 1985; Cousens, 1991; Radosevich 1987; Zimdahl 1980). Important parameters determined with an additive design include the critical weed density and biological threshold. The critical density is the weed density a crop can tolerate without exceeding an economically acceptable level of yield loss. The biological threshold is the weed density above which little or no further yield loss occurs.

The critical nutsedge density and biological threshold have been reported for several vegetable crops. In a greenhouse study by Morales-Payan et al. (1997), the critical purple nutsedge density for 10% bell pepper fruit yield loss was obtained with an initial density of 50 nutsedge plants$\cdot$m^{-2}. In their study, pepper fruit yield loss increased linearly to 32% as initial nutsedge density increased from 0 to 200 plants$\cdot$m^{-2}. Thus, the nutsedge density resulting in the biological threshold was not reached. In a field study by Morales-Payan (1999), yellow nutsedge interference by plants from less than 25 tubers$\cdot$m^{-2} reduced marketable tomato fruit yield by 10%. In the same study, nutsedge interference reduced marketable tomato fruit yield by approximately 45% with initial

nutsedge densities of 50 to 200 plants·m^{-2}. The biological threshold for tomato yield loss, then, was obtained with 50 nutsedge plants·m^{-2}.

Crop response to weed density may vary with production practices used. For example, applied N rate and purple nutsedge tuber density interacted in their effects on fruit yield of greenhouse-grown bell pepper (Morales-Payan et al., 1998). With 70 kg N·ha^{-1}, initial nutsedge plant density had no effect on bell pepper fruit yield. With 140 and 210 kg N·ha^{-1}, pepper yields declined linearly up to 73% with an increase in nutsedge density from 0 to 300 plants·m^{-2}.

Field-grown bell pepper yield response to yellow nutsedge population has not been described. This research was conducted to determine the effect of planted yellow nutsedge tuber densities on growth and fruit yield of bell pepper planted at two in-row spacings.

Materials and Methods

Design

Experiments were conducted during spring and fall on a Kanapaha fine sand (loamy siliceous, hyperthermic, Grossarenic Paleaquult) in 1999 and on an Arredondo fine sand (loamy, siliceous, hyperthermic, Grossarenic Paleudult) in 2000 at the Horticultural Research Unit of the University of Florida in Gainesville, Fla.

Treatments were arranged as a factorial with two in-row pepper spacings (22.9 and 30.5 cm) and five to six planted tuber densities with five replications. In spring 1999, 0, 30, 60, 90, and 120 tubers·m^{-2} were planted. In fall 1999, 0, 10, 20, 30, 60, and 90 tubers·m^{-2} were planted. In both seasons in 2000, 0, 15, 30, 45, 60, and 90 tubers·m^{-2} were planted.

Establishment and Maintenance Procedures

Beds were formed on 1.2 m centers, fumigated with 392 $kg \cdot ha^{-1}$ of 75:25 methyl bromide:chloropicrin injected 20 cm deep with two shanks to kill existing tubers, and covered with polyethylene mulch (Sonoco; 0.0038 cm thickness; black in spring; white in fall). Planting holes were punched within one to two weeks after fumigation, but in fall 1999 they were punched five weeks after fumigation due to a delay in availability of pepper transplants. Holes for pepper transplants were punched with a planting wheel to form double rows of holes spaced 22.9 or 30.5 cm apart in the rows. Holes for nutsedge tubers were punched via a board with dowels 7.6 cm long. For each season, the number of dowels on the board corresponded to the highest tuber density used so that all plots received the same number of holes.

Bell pepper ('X3R Camelot') seedling and nutsedge tuber planting began on the day holes were punched (Table 1-1). Each nutsedge planting hole received one tuber in plots treated with the highest tuber density. In remaining plots, the number of holes planted varied according to tuber density. For example, in spring 2000, a maximum of 120 $tubers \cdot m^{-2}$ was planted. To plant 60 $tubers \cdot m^{-2}$, one of every two holes received a tuber. Within each treatment, the same spatial pattern of planted tubers was used.

Drip irrigation with biwall tubing (orifice diameter, 0.025 cm; emitter spacing, 30 cm; flow rate of 1.89 L per 30.5 m per min) placed on the soil surface at the middle of each bed simultaneously with polyethylene mulch application was used to supply water as needed to prevent moisture stress to plants. Irrigation times for each week were scheduled to apply approximately 75% of the mean daily volume of ET for the previous seven days.

Plants received 224:37:186 kg ha^{-1} of N-P-K, respectively. All P and 40% of N and K were applied preplant-incorporated during bed formation. The remainder of N and K was drip-applied in 10 equal weekly applications. Pesticides were applied as needed for insect and disease control.

Measured and Derived Variables

Measured variables included pepper and nutsedge plant height, pepper leaf area, dry weight of pepper [(leaves, stem, and fruit (if present)] and nutsedge (shoots) plants, nutsedge shoot number, N concentration in pepper and nutsedge plants, and harvested pepper fruit weight. Pepper leaf, stem, and fruit dry weights were summed to obtain total dry weight per pepper plant. Using dry weight data from pepper plants grown weed-free, percent losses of leaf, stem, fruit, and total dry weight were calculated.

Nitrogen concentration in pepper was determined for leaf, stem, and fruit tissue. The N concentrations were determined for fruit on pepper plants sampled before harvest and for harvested fruit. When no fruit was present, a value of zero was assigned for N concentration and N accumulation. Accumulation of N by pepper leaf, stem, and fruit tissue was the product of N concentration multiplied by dry weight. Dry weight of harvested fruit was calculated multiplying the fresh weight of harvested fruit by percent dry weight of a sample of harvested fruit. During each season, fruit N uptake for each harvest was summed to obtain total fruit N uptake. In a similar manner as for dry weight data, percent losses of leaf, stem, fruit, and total N uptake were also determined.

Nutsedge N uptake was derived the same as for pepper leaf and stem N uptake. Methods for determining nutsedge dry weight per unit land area, however, differed in 1999 and 2000. In 1999, nutsedge shoot N uptake was derived by multiplying the dry

weight of a known number of sampled stems by the number of shoots in a unit area of bed surface. In 2000, nutsedge shoot N uptake was derived using the dry weight of all shoot biomass within the unit of land area.

Harvested pepper fruit weight data for each harvest were summed to obtain total fruit weight for each fruit size category. Large fruit yield was derived from the sum of U.S. Fancy and U.S. No. 1 fruit. Yields of U.S. Fancy, U.S. No. 1 and U.S. No. 2 fruit were summed to obtain marketable fruit yield. Total yield was the sum of yield for all fruit grades including culls. Harvested fruit yields were converted to percent loss, relative to values obtained with pepper grown weed-free.

Data Collection Procedures

Pepper plant heights, the distance from the bed surface to the highest bud, were measured during flowering, fruit development, and after final fruit harvest (Table 1-1) from four representative plants in the middle of each plot. A stake, placed in the ground at pepper flowering, was used to show the location of the four plants so that height data were collected from the same plant each time.

Nutsedge shoot heights, the distance from the bed surface to the highest growing point of leaf blades, were measured at the same times as pepper plant heights (Table 1-1) from eight leaf blades in the middle of each plot.

Nutsedge shoots were counted in a 0.1 m^2 area in each plot during pepper flowering, fruit development, and after final fruit harvest (Table 1-1). In 1999, shoots were counted in the middle of each plot where shoot heights were obtained. To avoid compromising shoot height data, heights were obtained from leaf blades that appeared

undisturbed, or heights were measured before shoot counting. In 2000, shoots were counted at one end of each plot in a 0.1 m^2 area with nutsedge and pepper end-plants.

Nutsedge shoots were sampled in a 0.1 m^2 area at one end of each plot the same times as shoots were counted (Table 1-1). Shoots were sampled by cutting at ground level. In 1999, a portion (14 to 28 shoots) of the shoots in the 0.1 m^2 area was sampled. In 2000, to improve the likelihood of obtaining a representative sample, all of the shoots in the 0.1 m^2 area were sampled. Each sample of shoots was placed in a labeled paper bag and dried in a forced air drier at 60 °C prior to recording dry weight. Subsequently, samples were ground with a mill (Wiley) to a particle size of < 0.6 mm diameter prior to determining total kjeldahl N (TKN) using a 100 mg sample. Tissue were digested in H_2SO_4 and analyzed by Rapid Flow Colorimetry (Hanlon et al., 1996).

In each season, a representative pepper plant from each end of every plot was sampled during pepper flowering, fruit development, and near the end of fruit harvesting (Table 1-1). In plots with nutsedge, pepper plants surrounded by nutsedge were sampled. Leaves, stem, and fruit(s) (if present) of each plant were separated and placed in bags after passing leaves through an area meter (LI-3100; LI-COR; Lincoln, NE) to obtain total leaf-plus-petiole area per pepper plant. Leaf, stem, and fruit tissue were dried at 60 °C prior to recording dry weight for leaf, stem, and fruit (if present) tissue. Dried tissue was then analyzed for TKN in the same mannner as above. Pepper leaf and stem tissue sampled at pepper flowering were combined for TKN analysis. For plants sampled during fruit development and after fruit havest, TKN was determined for leaf, stem, and fruit (present only during fruit development) tissue.

In spring and fall 2000, light (photosynthetic photon flux density) readings were taken via a radiometer-photometer (LI-250; LI-COR; Lincoln, Neb.) with a one meter long quantum sensor (LI-191SA; LI-COR; Lincoln Neb.) at pepper flowering and fruit development. In each plot with nutsedge, a reading was taken one meter above the tallest plants to determine the amount of light available to pepper and nutsedge plants. A second reading was taken with the sensor placed flush with the top of the pepper plants with nutsedge leaf blades laying over the bar. The second reading was divided by the first and multiplied by 100 with the resulting percentage subtracted from 100.

Pepper fruits were harvested twice each season except for fall 1999 when fruits were harvested once. After removing culls, fruit were graded as US fancy, US No. 1, and US No. 2 fruit according to U.S. Dept. of Agriculture standards.

Data Analysis Procedures

Data were subjected to analysis of variance using SAS (SAS, 2000). Significant effects were obtained with F-tests. Because densities lower than 30 tubers·m^{-2} varied between spring 1999 and fall 1999 seasons, data for these seasons were analyzed separately. Tuber densities in spring 2000 and fall 2000 were the same, so data for these seasons were combined for analysis.

Pepper fruit yield and vegetative dry weight data were expressed as weight and as percent weight loss relative to weight obtained with no nutsedge. Pepper fruit and vegetative yield responses to increased tuber densities were described with polynomial contrasts. Analysis of interactions were performed on percent loss data. Bell pepper fruit reduction by nutsedge was regressed against tuber density using a rectangular hyperbola model proposed by Cousens (1985): $Y = ID/(1 + ID/A)$ where Y = yield loss, D = initial

tuber density, I = yield loss as D approaches 0, and A = maximum yield loss as D approaches infinity. Values for vegetative growth responses to tuber density were regressed using a rectangular hyperbola: $Y = A \times X/(B + X)$ where 'Y' = percent loss, 'X' = initial tuber density, 'A' = maximum percent loss, and 'B' = a random parameter. All curves generated with hyperbolic equations originated at zero. Responses of nutsedge growth parameters and shoot N concentration and uptake to increased initial nutsedge plant density were described with polynomial contrasts.

Results and Discussion

Common planted-tuber densities in all seasons were 30, 60, and 90 tubers tubers$\cdot$m^{-2}. These tuber densities corresponded to the high range of bell pepper fruit and vegetative yield reduction by nutsedge interference. Thus, in fall 1999, tuber densities of 10 and 20 tubers$\cdot$m^{-2} were added and the 120 tubers$\cdot$m^{-2} density omitted. During each season in 2000, a density of 15 tubers$\cdot$m^{-2} was used in place of the 10 and 20 tubers$\cdot$m^{-2} densities. Although each planted tuber may have produced more than one shoot, initial tuber density was considered the same as initial plant density in discussion below.

Pepper Fruit Yield

Main treatment effects on pepper fruit yield are shown in Tables 1-2, 1-3, and 1-4. In spring 1999, large, marketable, and total fruit weights as t$\cdot$ha^{-1} were greater and losses as percent of yield with pepper grown weed-free were less with pepper plants spaced 23 than 31 cm apart within rows (Table 1-2). In-row pepper spacing in fall 1999 did not affect pepper fruit weight (Table 1-3).

In 2000, bell pepper fruit yield losses due to nutsedge interference were greater in fall than spring (Table 1-4) due to greater early-season nutsedge vigor as explained

below. Season interacted with in-row pepper plant spacing on large fruit weight as $t \cdot ha^{-1}$ but not as percent reduction by nutsedge interference. Nutsedge interference reduced large fruit weight (%) to a greater extent with pepper plants spaced 31 than 23 cm apart (Table 1-4). Marketable fruit weights were similar with in-row pepper spacings, but percent loss of marketable fruit due to nutsedge interference was 4% greater with pepper plants spaced 31 than 23 cm apart within rows. Pepper plants produced more total fruit weight when grown 23 than 31 cm apart, but total fruit weight loss (%) compared to pepper grown without nutsedge was greater with pepper plants spaced 31 than 23 cm apart.

It appeared that increasing pepper population by reducing in-row pepper plant spacing from 31 to 23 cm allowed pepper plants to more effectively compete with nutsedge. Therefore, intraspecific competition of pepper with itself was not as important as interspecific competition of pepper with nutsedge. With weeds controlled, Locascio and Stall (1994) reported similar bell pepper yields with in-row plant spacings of 23 and 31 cm with greater yield per plant with the 31 than 23 in-row pepper spacing.

Nutsedge interference in each season in 1999 reduced bell pepper fruit yields relative to yields obtained with pepper grown weed-free (Tables 1-2 and 1-3). Yield responses to plant density in spring 1999 were linear (Table 1-2), but were quadratic in fall 1999 (Table 1-3) and quadratic or cubic in 2000 (Table 1-4).

Rectangular hyperbolas generated for percent yield loss responses to nutsedge plant density are shown in Fig. 1-1. In spring 1999, fall 1999, and in 2000, the rate of yield loss was most rapid between 0 and 30 $plants \cdot m^{-2}$. Nutsedge interference with plants from 30 $plants \cdot m^{-2}$ reduced bell pepper fruit yields by 55% to 70%. Yield losses (%)

continued to increase with nutsedge densities greater than 30 plants$\cdot$m^{-2}, but they increased less sharply than between 0 and 30 plants$\cdot$m^{-2}. In all seasons, the critical planted nutsedge density resulting in 10% large, marketable, or total pepper fruit weight loss was predicted with less than 5 plants$\cdot$m^{-2}, and the biological threshold was predicted to be 30 to 45 plants$\cdot$m^{-2}.

Coefficients for model parameters for each fruit grade are shown in Table 1-5. Coefficients for parameter 'A' (yield loss with tuber density approaching infinity) showed that, with continued increases in nutsedge density beyond 90 or 120 plants$\cdot$m^{-2}, yield losses were expected to plateau at 90% to 100%.

Yield loss responses to initial nutsedge plant density in 2000 were not as well correlated (low r^2 values) as those in spring 1999 and fall 1999 (Fig.1-1), possibly a result in 2000 of regressing yield loss data within means from two seasons. Regressing the means would have increased the r^2 values. Slopes, though not as well correlated, resembled those obtained in spring 1999 and fall 1999.

Slopes generated by Cousen's model were similar in shape to those obtained by Morales-Payan (1999) for tomato yield loss to yellow nutsedge interference. Comparing his results with those in the present study, however, showed that tomato was more competitive to yellow nutsedge interference than bell pepper. For instance, the critical nutsedge density for 10% loss of marketable bell pepper and tomato fruit yield was 5 and 12 plants$\cdot$m^{-2}, and the tuber density resulting in the biological threshold resulted in 45% and over 60% yield loss for bell pepper and tomato, respectively. Tomato plants are taller and form a larger leaf canopy than pepper plants and are, thus, better able to compete with nutsedge. The low tolerance of bell pepper to yellow nutsedge interference suggested that

near total control of yellow nutsedge tubers is needed for acceptable pepper fruit production.

Pepper Height

Bell pepper height data are shown in Tables 1-6, 1-7, and 1-8. In spring 1999 (Table 1-6) and fall 1999 (Table1-7), in-row spacing of pepper plants had no influence on pepper plant heights. In 2000, pepper plants at fruit harvest were taller in spring than fall and in-row pepper spacing had no influence on pepper plant heights (Table 1-8).

In spring 1999 (Table 1-6) and fall 1999 (Table 1-7), mean nutsedge density influenced height of peppers compared to heights with no nutsedge. In spring 1999, pepper plants were shorter without than with nutsedge interference. In contrast, fall 1999 pepper plants were shorter with than without nutsedge interference. In 2000, nutsedge interference had no effect on pepper plant heights (Table 1-8).

In spring 1999, initial nutsedge plant density influenced pepper plant height during but not after pepper flowering (Table 1-6). At that time, pepper plant height increased quadratically from 23 to 27 cm with an increase in planted nutsedge density from 30 to 120 plants$\cdot$m^{-2}. Most of the height gain was between pepper flowering and fruit development.

In fall 1999, at each time they were recorded, pepper plant heights declined linearly from about 33 to 25 cm with an increase in nutsedge density from 10 to 90 plants$\cdot$m^{-2}. Pepper plant heights increased little between pepper flowering and the end of the season.

In 2000, initial nutsedge plant density interacted with season on pepper plant height during pepper flowering and fruit development (Tables 1-8 and 1-9). At these

times, pepper plant heights in spring 2000 either increased or changed little while, in fall 2000, they declined in cubic or linear fashion with an increase in planted nutsedge density from 15 to 90 plants$\cdot$m^{-2} (Table 1-9). Pepper plant heights after fruit harvest, averaged over both seasons in 2000, changed little with an increase in initial nutsedge density from 15 to 90 plants$\cdot$m^{-2} (Table 1-8).

Pepper plant heights responded to nutsedge interference differently in spring vs. fall seasons. In spring seasons (Tables 1-6 and 1-9), pepper plants grown with nutsedge were able to compete with nutsedge, whereas fall-season pepper plants (Tables 1-7 and 1-9) did not appear to be able to compete with nutsedge plants. These data suggested that pepper plants were more competitive in spring than fall.

Pepper Plant Leaf Number

Main effects of treatments on pepper leaf number are shown in Tables 1-10, 1-11, and 1-12. In spring 1999, leaf counts were not obtained from pepper plants sampled during pepper flowering (Table 1-10). In-row pepper plant spacing in spring 1999 only influenced leaf number loss (%) at pepper fruit development when reduction (%) in leaf number was greater with pepper plants spaced 31 than 23 cm apart. In fall 1999, leaf number was not influenced by in-row pepper plant spacing (Table 1-11).

In 2000, pepper plants sampled during pepper flowering, fruit development and after final fruit harvest produced more leaves in the spring than fall, but reductions (%) of leaf number due to nutsedge interference were similar between seasons (Table 1-12). In-row pepper spacing, during 2000, did not influence leaf number of plants sampled during pepper flowering. At fruit development, leaf numbers were similar with both in-row pepper spacings, but nutsedge interference reduced leaf number (%) to a greater extent

with pepper plants spaced 31 than 23 cm. At final fruit harvest, pepper had more leaves when grown 31 than 23 cm apart, and leaf number reduction (%) was greater with pepper plants spaced 31 than 23 cm apart.

In all seasons, nutsedge interference reduced pepper plant leaf number compared to that with no nutsedge (Tables 1-10, 1-11, and 1-12). Leaf number responses to initial nutsedge plant density were linear in spring 1999 (Table 1-10), quadratic in fall 1999 (Table 1-11) and linear or quadratic in 2000 (Table 1-12). Leaf numbers decreased while leaf number reductions (%) by nutsedge interference increased with increases in planted nutsedge density.

Rectangular hyperbolas for leaf number reduction by nutsedge interference are shown in Fig. 1-2. At pepper flowering, leaf number loss (%) increased more sharply in fall 1999 than in 2000 with increases in inital nutsedge plant density. In fall 1999, the rate of leaf number loss (%) at each sampling time appeared similar while in 2000, the rate of leaf number loss (%) was less pronounced at pepper flowering than at pepper fruit development or after fruit harvest. At pepper fruit development and after fruit harvest, in all seasons, leaf number loss (%) increased more sharply with an increase in planted nutsedge density between 0 and 30 than between 30 to 90 or 120 plants$\cdot$m^{-2}.

According to models for slopes in Fig 1-2, nutsedge plants from less than 5 tubers$\cdot$m^{-2} resulted in the critical density for 10% reduction in leaf number of pepper plants, except at pepper flowering in 2000 where 9 plants$\cdot$m^{-2} resulted in 10% leaf number reduction. The biological threshold was predicted to be with an initial nutsedge density of 30 plants$\cdot$m^{-2} for each sampling time except pepper flowering in 2000. At pepper flowering in 2000, the biological threshold was not reached.

Coefficients for model parameters of rectangular hyperbolas used to describe leaf number loss to nutsedge interference are shown in Table 1-13. Models predicted maximum leaf number reduction by nutsedge interference of 75% to 91%.

Pepper Plant Leaf Area

Main effects of treatments on pepper plant leaf area are shown in Tables 1-14, 1-15, and 1-16. In-row spacing in spring 1999 only influenced leaf area, as cm^2, of pepper at the end of the season (Table 1-14) and had no effect in fall 1999 (Table 1-15).

At each sampling time in 2000, leaf area of spring-grown pepper plants exceeded that of fall-grown pepper, but leaf area reduction (%) by nutsedge interference in fall and spring was similar (Table 1-16). In-row pepper spacing in 2000 did not influence pepper plant leaf area until pepper fruit development stage. At fruit development and at the end of the season, leaf areas were greater with pepper plants spaced 31 than 23 cm apart, but leaf area reductions (%) by nutsedge interference were similar with both pepper plant spacings.

Nutsedge interference consistently reduced pepper plant leaf area compared to leaf area with no nutsedge planted, and leaf area decreased while leaf area losses (%) increased with increases in nutsedge plant density (Tables 1-14, 1-15, and 1-16). Leaf area losses (%) by nutsedge interference were characterized by rectangular hyperbolas as shown in Fig.1-3. The rate of leaf area loss with pepper plants sampled during pepper flowering was more pronounced in fall 1999 than in spring 1999 and spring and fall of 2000. In spring 1999, the rate of increase in pepper leaf area reduction (%) was slightly greater for plants sampled during pepper fruit development than after fruit harvest. In fall 1999 and in spring and fall of 2000, rates of leaf area reduction (%) at fruit development

appeared similar as at the end of the season. Except at pepper flowering in spring 1999, leaf area losses (%) increased most sharply (to between 40% and 60%) with an increase in initial nutsedge density from 0 to 30 plants$\cdot$m^{-2}. At pepper flowering in spring 1999, nutsedge interference with 12 plants$\cdot$m^{-2} reduced leaf area by 10%, and the biological threshold was not reached. At remaining sampling times and seasons, the critical density for 10% leaf area reduction by nutsedge interference was predicted at less than 5 plants$\cdot$m^{-2}, and the biological threshold was reached with 30 to 45 plants$\cdot$m^{-2}.

Coefficients for model parameters characterizing the effect of nutsedge tuber density on leaf area reduction by nutsedge interference are shown in Table 1-17. Nutsedge interference was predicted to reduce leaf area by a maximum of 67% to 99%.

Pepper Leaf Dry Weight

Main effects of treatment on bell pepper leaf dry weight are shown in Tables 1-18, 1-19, and 1-20. In spring 1999, pepper plant in-row spacing did not affect pepper plant leaf dry weight until after fruit harvest (Table 1-18). After pepper fruit harvest, pepper plants produced more leaf biomass when spaced 31 than 23 cm apart, but nutsedge interference reduced leaf biomass similarly with both pepper plant spacings. In fall 1999, in-row pepper plant spacing did not influence pepper leaf dry weight (Table 1-19).

At each sampling time in 2000, leaf dry weights were greater while leaf dry weight losses (%) were less in spring than fall (Table 1-20). In row pepper spacing in 2000 did not affect leaf dry weight of pepper plants at pepper flowering, but at fruit development and after fruit harvest more leaf biomass (g$\cdot$plant^{-1}) and less leaf biomass loss (%) resulted from the 31- than 23-cm pepper spacing.

Nutsedge interference consistently reduced pepper leaf dry weights relative to weights with pepper grown weed-free (Tables 1-18, 1-19 and 1-20). Leaf dry weights decreased while leaf dry weight losses (%) increased with increases in initial nutsedge plant density, and responses were mostly linear in spring 1999 and quadratic in the other seasons.

Slopes generated with rectangular hyperbola models for the effect of initial nutsedge plant density on pepper leaf dry weight are shown in Fig. 1-4. Parameter coefficients for these slopes are shown in Table 1-21. Slopes for leaf dry weight loss resembled those for leaf area (Fig. 1-3). Pepper leaf dry weights at pepper flowering were reduced by nutsedge interference, relative to that with no nutsedge, 20% and 30% with 30 plants$\cdot m^{-2}$ and 40% and 60% with 90 plants$\cdot m^{-2}$ in spring 1999 and in 2000, respectively. At or after pepper fruit development in each season, leaf dry weight losses with a planted nutsedge density of 30 plants$\cdot m^{-2}$ were not greatly increased with further increases in nutsedge density.

Models showed that at pepper flowering in spring 1999 and in 2000, bell pepper tolerated interference by nutsedge plants from 7 to 12 tubers$\cdot m^{-2}$ without a greater than 10% reduction in leaf dry weight, and the biological threshold for leaf dry weight loss was not reached. At flowering in fall 1999 and at or after fruit development in each season, the critical initial nutsedge density for 10% dry weight loss was predicted with less than 5 plants$\cdot m^{-2}$, and the biological threshold was reached with 30 plants$\cdot m^{-2}$.

Pepper Stem Dry Weight

Main effects of treatments on stem dry weight are shown in Tables 1-22, 1-23, and 1-24. In spring 1999 at pepper flowering, pepper plants produced a similar amount of

stem biomass with both in-row spacings, but nutsedge interference at pepper flowering and harvest times reduced stem dry weights (%) to a greater extent with plants spaced 31 than 23 cm apart (Table 1-22). Apparently, during pepper flowering, nutsedge interference had a greater effect on stem biomass than leaf biomass production as leaf biomass losses (%) were similar with both pepper plant spacings (Table 1-18). During pepper fruit development in spring 1999, in-row pepper spacing had no effect on stem dry weight (Table 1-22). After fruit harvest, plants produced more stem biomass with pepper plants spaced 31 than 23 cm apart, but stem dry weight losses (%) were similar with both pepper plant spacings. In fall 1999, in-row pepper spacing did not affect pepper stem dry weights (Table 1-23).

In 2000, stem dry weights were much greater, and losses (%) were 25% to 50% less with pepper plants grown in spring than fall (Table 1-24). In-row pepper spacing had no or little effect on pepper stem dry weights in spring and fall 2000.

In all seasons, nutsedge interference reduced stem dry weights compared to those with pepper grown weed-free (Tables 1-22, 1-23, and 1-24). Furthermore, in all seasons, pepper stem dry weights decreased while dry weight losses (%) increased with increases in initial nutsedge plant density. These responses were linear or cubic in spring 1999 (Table 1-22) and quadratic in the other seasons (Tables 1-23 and 1-24).

Slopes and model parameter coefficients for stem dry weight reduction (%) by nutsedge interference are shown in Fig. 1-5 and Table 1-25, respectively. These slopes appeared similar to those observed for leaf area (Fig. 1-3) and leaf dry weight (Fig. 1-4), except that, at pepper flowering in spring 1999, stem dry weight loss increased linearly from about 8% to 30% with an increase in initial nutsedge density from 30 to 120

plants·m^{-2}. Similarly, in spring and fall 2000 during pepper flowering, stem dry weight loss increased from 12% to 50% with an increase in nutsedge density from 15 to 90 plants·m^{-2}. (Fig. 1-5). At flowering in fall 1999 and during or after fruit development in each season, pepper plant stem dry weight losses (%) increased rapidly to over 45% with an initial nutsedge density of 30 plants·m^{-2} and less sharply with further increases in nutsedge plant density.

Bell pepper plants sampled during flowering in spring 1999 and in 2000 tolerated nutsedge interference with plants from 10 and 33 planted tubers·m^{-2}, respectively, without a greater than 10% reduction in stem dry weight. In these seasons, the biological threshold for leaf dry weight loss was not reached. At flowering in fall 1999 and during or after fruit development in each season, the critical initial nutsedge density for 10% loss and biological threshold was predicted with less than 5 plants·m^{-2} and with 30 plants·m^{-2}, respectively.

Pepper Fruit Dry Weight During Fruit Development Stage

Main effects of treatments on dry weight of fruit present on pepper plants sampled during fruit development are shown in Tables 1-26 and 1-27. In spring 1999, fruit dry weights were similar with both in-row pepper plant spacings, but percent dry weight loss of 75% with pepper plants spaced 31 cm apart was slightly greater than that with plants spaced 23 cm apart (Table 1-26). In fall 1999, in-row pepper spacing had no effect on dry weight of developing fruit.

In 2000, during the pepper fruit development stage, fruit dry weights were much greater in spring than fall, but percent losses of approximately 60% were similar in both

seasons (Table 1-27). In-row pepper spacing in spring and fall 2000 did not influence dry weight of enlarging fruit.

In all seasons, nutsedge interference substantially reduced fruit dry weights compared to those with no nutsedge (Tables 1-26 and 1-27). Fruit dry weights decreased whereas losses (%) increased with increases in nutsedge plant density. These responses to nutsedge density were linear in spring 1999 and quadratic in the other seasons.

Rectangular hyperbolas and coefficients for model parameters are shown in Fig. 1-6 and Table 1-28, respectively. Slopes for each season were similar in shape and magnitude (Fig. 1-6). In each season, percent dry weight loss of developing fruit increased rapidly to nearly 60% with nutsedge interference from 30 plants$\cdot m^{-2}$ and increased more slowly to between 70% and 80% with 90 or 120 plants$\cdot m^{-2}$. Thus, in all seasons, the critical nutsedge density for 10% reduction in dry weight and the biological threshold was predicted with less than 5 and with 30 plants$\cdot m^{-2}$, respectively.

Rectangular hyperbolas for developing (Fig. 1-6) and harvested (Fig. 1-1) fruit weight as well as fruit number (data not shown) were similar. Therefore, nutsedge interference significantly reduced bell pepper fruit set and enlargement.

<u>Pepper Plant Total Dry Weight</u>

Main effects of treatments on total bell pepper dry weight [sum of leaf, stem, and fruit (if present) dry weight] are shown in Tables 1-29, 1-30, and 1-31. In spring 1999 during pepper flowering, in-row pepper spacing did not influence total biomass produced by pepper plants, but percent loss of biomass due to nutsedge interference was greater with pepper plants spaced 31 than 23 cm apart (Table 1-29). During pepper fruit development, in-row pepper spacing had no influence on total pepper plant biomass.

After final pepper fruit harvest, total dry weight of pepper plants was slightly greater with pepper plants spaced 31 than 23 cm apart, and biomass loss (%) due to nutsedge interference was similar with both in-row pepper plant spacings. In fall 1999, in-row pepper spacing had no influence on the dry weight of total biomass produced by pepper plants (Table 1-30).

In 2000, total pepper biomass was greater and biomass loss (%) was less in spring than fall (Table 1-31), and this was consistent with results in 1999. For example, at pepper flowering, nutsedge interference reduced total pepper biomass by 30% to 41% in spring 1999 (Table 1-29) compared to 63% to 64% in fall 1999 (Table 1-30). These findings were in agreement with those for all pepper growth parameters and showed that nutsedge interfered more strongly with bell pepper vegetative growth in fall than spring.

In spring and fall 2000, in-row spacing of pepper plants had little or no effect on the dry weight of total biomass produced by pepper plants at or after pepper flowering (Table 1-31). This was also true for pepper leaf, stem and developing fruit dry weights in 2000 and for pepper growth parameters in fall 1999. Therefore, only in spring 1999 did increased pepper plant populations with plants spaced 23 cm compared to 31 cm apart improve pepper plant competitiveness against yellow nutsedge. In all seasons, however, yellow nutsedge interference substantially reduced bell pepper plant growth.

As for previously discussed growth parameters, nutsedge interference reduced total pepper biomass in all seasons compared to that with no nutsedge (Tables 1-29, 1-30, and 1-31). Therefore, yellow nutsedge interference significantly reduced bell pepper fruit yield and plant size.

Total pepper plant biomass decreased while biomass loss (%) increased with increases in nutsedge plant density (Tables 1-29, 1-30, and 1-31). As for other growth parameters previously discussed, these nutsedge density effects were usually linear in spring 1999 (Table 1-29) and quadratic or cubic in the other seasons (Tables 1-30 and 1-31).

Rectangular hyperbolas and coefficients for model parameters describing the effects on initial nutsedge plant density on total pepper biomass are shown in Fig. 1-7 and Table 1-32, respectively. The shape and magnitude of slopes shown in Fig. 1-7 resembled those for leaf number (Fig. 1-2), leaf area (Fig 1-3), and dry weight of leaves (Fig. 1-4) and stems (Fig. 1-5). The effects of nutsedge interference on pepper growth in spring 1999 and in 2000, as shown by data for these variables, were more obvious during and after pepper fruit development than during pepper flowering. This was evidenced by higher coefficient of determination (r^2) values for data obtained during than after pepper flowering. Even at 6 WAT during pepper flowering, however, nutsedge interference substantially reduced pepper plant size, especially with 30 or more plants$\cdot$m^{-2}. For instance, total pepper plant biomass of pepper plants sampled 6 WAT in spring 1999 and in 2000 was reduced by over 45% with 90 nutsedge plants$\cdot$m^{-2} (Fig. 1-7).

Interspecific nutsedge competition with pepper was dominant during pepper flowering in spring 1999 and in 2000 as shown by linear or nearly linear increases in biomass loss with increases in nutsedge plant density (Figures 1-4, 1-5, and 1-7). During and after pepper fruit development in spring 1999 and in spring and fall 2000, loss percentages for each pepper growth parameter increased less sharply with an increase in initial nutsedge density from 30 to 90 or 120 than between 0 and 30 plants$\cdot$m^{-2}.

Intraspecific nutsedge competition, therefore, increased with time from pepper flowering to fruit development and with increases in nutsedge plant density from 30 to 90 or 120 plants·m^{-2}. By pepper flowering in fall 1999, however, nutsedge had already substantially interfered with bell pepper growth as indicated by high percent losses for pepper growth parameters and by higher r^2 values obtained for plants sampled during than after pepper flowering.

For all growth parameters discussed above, the highest r^2 values were obtained when nutsedge interference with pepper growth was most severe. At remaining times, low r^2 indicated that nutsedge interference did not consistently result in the losses (%) indicated by the regression models.

Pepper Plant and Fruit N Concentration

Concentration of N in bell pepper plant tissues was measured to determine if N was a common resource competed for by yellow nutsedge and bell pepper. Main effects of treatments on bell pepper N concentration in plant (leaf and stem tissue) and fruit tissue are shown in Tables 1-33, 1-34, and 1-35. In-row pepper plant spacing did not influence pepper plant and fruit N concentration in spring 1999 (Table 1-33). In fall 1999, plant N concentrations were slightly greater with pepper plants grown 31 than 23 cm apart within rows, but in-row pepper plant spacing did not affect pepper fruit N concentration (Table 1-34).

In 2000, season had no effect on pepper plant N concentration during pepper flowering, but plant N concentrations after pepper flowering were greater in fall than spring (Table 1-35). In-row pepper plant spacing in 2000 did not affect pepper plant N or developing fruit N concentration. Harvested fruit N concentrations, however, were 10%

greater with pepper plants spaced 23 than 31 cm apart within rows, a result consistent with that of less yield loss (%) with pepper plants spaced 23 than 31 cm apart (Table 1-4).

Nutsedge interference in spring 1999 reduced plant N concentration, relative to that with plants grown weed-free, during pepper flowering and after final fruit harvest but not during fruit development (Table 1-33). Nutsedge interference had no effect on pepper fruit N concentration in spring 1999. In fall 1999, nutsedge interference appeared to increase concentrations of N in vegetative tissue of pepper plants sampled after fruit harvest and in harvested fruit (Table 1-34). In spring and fall 2000, plant and fruit N concentrations were greater without than with nutsedge interference, except for end-of-season plant N concentration that was not influenced by nutsedge (Table 1-35).

In spring 1999, during pepper flowering, pepper plant N concentration declined linearly from 4.22% to 3.72% with an increase in nutsedge plant density from 30 to 120 plants$\cdot$m^{-2} (Table 1-33). Tuber density did not differentially influence pepper plant N concentration during pepper fruit development, but N concentration after fruit harvest declined linearly from 1.85% to 1.56% with an increase in initial nutsedge density from 30 to 120 plants$\cdot$m^{-2}. Concentrations of N in immature and harvested fruit were similar with all planted nutsedge densities.

With an increase in initial nutsedge density from 10 to 90 plants$\cdot$m^{-2} in fall 1999, N concentration in pepper plant tissue sampled during pepper flowering increased linearly from 2.80% to 3.46% (Table 1-34). During pepper fruit development, the effect of nutsedge plant density on pepper plant N concentration was quadratic, but changes in N concentration over the range of tuber densities used were slight. After pepper fruit harvest, pepper plant N concentration increased linearly from 2.17% to 2.74% with an

increase in initial nutsedge density from 10 to 90 plants$\cdot$m^{-2}. Nitrogen concentration in immature pepper fruit decreased linearly from 1.97% to 1.62% while N concentration in harvested fruit remained constant with an increase in nutsedge density from 10 to 90 plants$\cdot$m^{-2}.

In 2000, at pepper flowering, plant N concentrations decreased quadratically from 2.85% to 2.55% with an increase in initial nutsedge density from 15 to 90 plants$\cdot$m^{-2} (Table 1-35). Pepper plant N concentrations after pepper flowering were not differentially influenced by nutsedge interference at the tuber densities used.

In 2000, season and initial nutsedge density interacted in their effects on developing and harvested pepper fruit N concentration (Tables 1-35 and 1-36). Nutsedge interference reduced fruit N concentration with the exception of N concentration in harvested spring-season fruit (Table 1-36). The major source of the interaction was that N concentrations in immature and harvested fruit changed little in spring and decreased in fall with increases in planted nutsedge density. Linear decreases in immature and harvested fall-season fruit N concentrations with increases in initial nutsedge plant density were due to the absence of fruit on some pepper plants grown with nutsedge.

According to Lorenz and Maynard (1988), 2.5% to 3.5% N of leaf dry weight was sufficient for pepper plants at the full bloom stage. In the present study, plant (leaf and stem tissue combined) N concentrations with no nutsedge interference at 6 WAT were 4.7%, 2.9%, and 3.1% in spring 1999 (Table 1-33), fall 1999 (Table 1-34), and spring and fall 2000 (Table 1-35), respectively. During pepper fruit development and after fruit harvest, leaf N concentrations were up to 60% greater than stem N concentrations (data not shown). Therefore, N concentration at 6 WAT in leaf tissue alone would have been

greater than that with leaf and stem tissue combined. Thus, it appeared that pepper plants grown without nutsedge interference during each season contained a sufficient amount of N at 6 WAT.

Lorenz and Maynard (1988) reported a N sufficiency range for bell pepper of 1.5% to 2.5% dry weight of leaf tissue sampled at full bloom with fruits 75% of full size. Miller (1961) showed that 1.75% N of dry weight of fruit tissue was sufficient for bell pepper fruit. In the present study, spring-season pepper plant and fruit N concentrations during pepper flowering and fruit development were at least 2.28% (Tables 1-33 and 1-35). Therefore, nutsedge interference did not reduce pepper plant N concentration to a growth limiting concentration in spring seasons. The linear reduction of pepper plant N concentration in spring 1999 with increases in nutsedge plant density (Table 1-33) indicated that nutsedge competed with pepper for N. Therefore, under conditions of low soil fertility, nutsedge interference with pepper could reduce pepper growth and yield by reducing the amount of N available for pepper plants.

In fall seasons, plant N concentrations of at least 2.02% during pepper fruit development (Tables 1-34 and 1-35) exceeded 1.5%, the lowest concentration of N reported to be sufficient for pepper growth by Lorenz and Maynard (1988). Harvested fruit N concentration in fall 1999 exceeded 1.75% (Table 1-34), a sufficient concentration of N (Miller, 1961). In fall 2000, fruit N concentrations of less than 1.75% were observed (Table 1-36), but this was due to the lack of fruit in some plots that received nutsedge. Therefore, in fall seasons, N availability to pepper plants may have been reduced by nutsedge interference to growth limiting amounts, but N concentration data were not conclusive.

Pepper Plant N Uptake

Main effects of treatments on pepper plant (leaf plus stem) N uptake are shown in Tables 1-37, 1-38, and 1-39. In spring 1999, in-row pepper spacing influenced pepper plant N uptake at pepper flowering and fruit development but not at the end of the season (Table 1-37). At pepper flowering and fruit development, N accumulations in pepper plants were greater with pepper plants spaced 23 than 31 cm apart within rows. Loss (%) of N uptake at pepper flowering, however, was greater with pepper plants spaced 31 than 23 cm apart within rows. After pepper flowering in-row pepper spacing had no effect on pepper plant N accumulation.

In-row pepper spacing in fall 1999 did not influence pepper plant N uptake and only influenced plant N uptake reduction (%) by nutsedge interference at pepper fruit development (Table 1-38). At this time, nutsedge interference reduced pepper plant N uptake to a greater extent with pepper plants grown 31 than 23 cm apart within rows.

In 2000, spring-grown pepper plants sampled at each pepper growth stage had accumulated more plant N than those grown in fall (Table 1-39). Reduction (%) of plant N uptake, relative to that with no nutsedge, was similar in spring and fall at the pepper flowering stage. At the pepper fruit development stage, reduction (%) of plant N uptake by nutsedge interference was greater in fall than spring.

In 2000, pepper plant N accumulations at flowering and after fruit harvest were greater with plants spaced 23 than 31 cm apart, but in-row plant spacing had no effect on N uptake at fruit development (Table 1-39). Reduction (%) in plant N uptake at flowering was similar with plants spaced 23 than 31 cm, but at fruit development it was greater with plants spaced 31 than 23 cm apart. After pepper fruit harvest, season

interacted with in-row pepper plant spacing on pepper plant N uptake reduction (%) by nutsedge interference (Tables 1-39 and 1-40). In both seasons, nutsedge interference reduced pepper plant N uptake by at least 57%, but only in spring was the reduction percentage greater with pepper plants spaced 31 than 23 cm apart (Table 1-40).

During each season, nutsedge interference consistently reduced pepper plant N uptake compared to that with no nutsedge (Tables 1-37, 1-38, and 1-39). With increases in initial nutsedge plant density, pepper plant N uptake decreased while percent reduction of N uptake increased. An exception occurred in spring 1999 during pepper fruit development when pepper plant N uptake reduction by nutsedge interference remained constant at about 60% with all initial nutsedge plant densities (Table 1-37).

In spring 1999, nutsedge interference with plants from 30 tubers$\cdot$m^{-2} reduced pepper plant N uptake by 27% at pepper flowering compared to 57% and 52% during fruit development and after fruit harvest, respectively (Table 1-37). With further increases in initial nutsedge density, plant N reduction percentages increased more sharply during than after pepper flowering.

With an initial nutsedge density of 10 plants$\cdot$m^{-2} in fall 1999, nutsedge interference reduced pepper plant N uptake by at least 19%, and the effects of nutsedge interference were most obvious at pepper flowering when plant N uptake reduction increased from 38% to 82% with an increase in nutsedge density from 10 to 90 plants$\cdot$m^{-2} (Table 1-38).

In 2000, nutsedge interference with 15 plants$\cdot$m^{-2} reduced pepper plant N uptake by 24% at pepper flowering compared to 46% and 48% during pepper fruit development and after fruit harvest, respectively (Table 1-39). Nutsedge interference reduced pepper

plant N uptake in 2000 more severely after than during pepper flowering. In each season, at one or more of the pepper growth stages, nutsedge interference reduced pepper plant N uptake to a maximum of 70% or more (Table 1-37, 1-38, and 1-39).

During each season, coefficients of determination for plant N accumulation as percent loss of that with pepper grown weed-free were below 0.50. Slopes for plant N uptake reduction by nutsedge interference were not shown because the critical density for 10% reduction in plant N uptake could not be accurately predicted.

Pepper Fruit N Uptake

Main effects of treatments on pepper fruit N uptake are shown in Tables 1-41, 1-42, and 1-43. In spring 1999, pepper fruit in the development stage accumulated more N with pepper plants spaced 23 than 31 cm apart, but N uptake as percent loss, relative to that obtained with pepper grown weed-free, was similar with both pepper plant spacings (Table 1-41). Harvested fruit N uptake was slightly greater with pepper plants spaced 23 than 31 cm apart within rows, and N uptake reduction percentage was greater with pepper plants spaced 31 than 23 cm apart.

In fall 1999, in-row pepper spacing did not have a strong effect on pepper fruit N uptake (Table 1-42). Reduction of N (%) in immature fruit was greater with pepper plants spaced 31 than 23 cm apart within rows.

In 2000, immature and harvested pepper fruit accumulated about ten times more N in spring than fall, but reduction (%) of N taken up by immature fruit, relative to that with no nutsedge, was similar between seasons (Table 1-43). Harvested fruit N uptake reduction percentages were greater in fall than spring.

In-row pepper spacing in 2000 (Table 1-43) influenced developing and harvested fruit N uptake and N uptake reduction (%) by nutsedge interference in a similar manner as described in spring 1999 (Table 1-41). During spring 1999 (Table 1-41), fall 1999 (Table 1-42), and spring and fall of 2000 (Table 1-43), nutsedge interference reduced immature and harvested fruit N accumulation by at least 57% with either in-row pepper plant spacings.

In each season, nutsedge interference reduced immature and harvested fruit N uptake compared to that with no nutsedge (Tables 1-41, 1-42, and 1-43). Fruit N uptake decreased while N uptake reduction percentages increased with increases in nutsedge density. Initial nutsedge plant density effects on immature and harvested fruit N uptake were linear in spring 1999 (Table 1-41) and quadratic in the other seasons (Tables 1-42 and 1-43).

Rectangular hyperbolas for fruit N uptake reduction by nutsedge interference and coefficients for model parameters are shown in Fig 1-8 and Table 1-44, respectively. In each season the slopes for developing (immature) and harvested pepper fruit N uptake reduction by nutsedge interference were similar in shape and magnitude. They showed that most reduction in N uptake by pepper fruit of 50% to 60% occurred as initial nutsedge density was increased from 0 to 30 plants·m^{-2} (Fig. 1-8). With 90 nutsedge plants·m^{-2}, nutsedge interference reduced immature and harvested fruit N uptake by at least 70% in each season. In each season, the critical densities (for 10% reduction) and biological thresholds for immature and harvested fruit N uptake reduction by nutsedge interference were reached with less than 5 plants·m^{-2} and with 30 plants·m^{-2}, respectively.

Pepper Plant Plus Fruit N Uptake

Main effects of treatments on pepper plant plus fruit (total) N uptake during pepper fruit development and harvest time are shown in Tables 1-45, 1-46, and 1-47. In spring 1999, at pepper fruit development, plants accumulated more N when grown 23 than 31 cm apart, but reduction (%) of total N uptake by nutsedge interference was similar with both pepper plant in-row spacings (Table 1-45). Total pepper N uptake at harvest time was similar with both in-row pepper plant spacings while N uptake reduction (%) by nutsedge interference was 7% greater with pepper plants spaced 31 than 23 cm apart. In fall 1999, the only time in-row pepper spacing influenced total pepper N uptake was at fruit development when total N uptake reduction (%) was greater with plants spaced 31 than 23 cm apart (Table 1-46).

In 2000, at both sampling times, total N uptake was greater and reduction (%) by nutsedge of total pepper N uptake was less in spring than fall (Table 1-47). At pepper fruit development, bell pepper accumulated more total N when grown 23 than 31 cm apart within rows, but nutsedge interference reduced total pepper N uptake similarly with both in-row pepper plant spacings. Cumulative N uptake of pepper vegetative and fruit tissue at harvest time was greater with pepper plants spaced 23 than 31 cm apart, and reduction (%) of total pepper N uptake by nutsedge interference was 4% greater with pepper plants spaced 31 than 23 cm apart.

In each season and at each sampling time within seasons, nutsedge interference reduced total pepper N accumulation relative to that with no nutsedge (Tables 1-45, 1-46, and 1-47). Total N uptake decreased with increases in nutsedge plant density in each season. Percent reduction in total pepper N uptake increased linearly in spring 1999

(Table 1-45), quadratically in fall 1999 (Table 1-46), and in cubic fashion in spring and fall of 2000 (Table 1-47) with increases in nutsedge plant density.

Rectangular hyperbolas and model parameter coefficients generated for percent reduction by nutsedge interference of total pepper N accumulation are shown in Fig. 1-9 and Table 1-48, respectively. In each season, rates of increase in total N uptake reduction (%) with increases in nutsedge plant density were similar at pepper fruit development as at fruit harvest. Within each season, slopes for fruit N uptake (Fig. 1-8) and total N uptake (Fig. 1-9) reduction by nutsedge interference were similar in shape and magnitude. Hence, discussion and predicted parameters for fruit N uptake are applicable for total pepper N uptake.

Nitrogen accumulation by bell pepper was a function of plant dry weight and N concentration. Therefore, nutsedge competition reduced N uptake similarly as plant dry weight. Nutsedge interference consistently reduced pepper plant size and, thus, N uptake by pepper vegetative and fruit tissue.

Nutsedge Shoot Height and Number

Main effects of treatments on nutsedge shoot height and number in spring 1999, fall 1999, and spring and fall of 2000 are shown in Tables 1-49, 1-50, and 1-51, respectively. In spring 1999, in-row pepper plant spacing had no effect on shoot height, and only affected shoot number at pepper fruit harvest time when the number of shoots in a 0.1 m^2 area was 10% greater with pepper plants spaced 31 than 23 cm apart (Table 1-49). In fall 1999, in row pepper plant spacing only affected nutsedge shoot numbers during pepper fruit development (Table 1-50). At that time there were seven more nutsedge shoots per 0.1 m^2 with pepper plants spaced 31 than 23 cm apart within rows.

In 2000, at pepper fruit development and fruit harvest, nutsedge shoot heights and numbers were greater in spring than fall (Table 1-51). These results were consistent with those obtained in spring 1999 (Table 1-49) vs. those in fall 1999 (Table 1-50). They showed that nutsedge proliferation and growth declined with time during fall seasons.

Nutsedge shoots during pepper flowering in 2000 were less than 2 cm taller with pepper plants spaced 23 than 31 cm apart (Table 1-51). This was the only significant effect of in-row pepper plant spacing in 2000. Therefore, in-row pepper spacing did not have a strong effect on nutsedge shoot proliferation and height in any of the seasons during which the experiment was conducted.

In spring 1999, nutsedge shoot height during pepper flowering increased linearly from 45 to 53 cm with an increase in nutsedge density from 30 to 120 plants$\cdot$m^{-2} (Table 1-49), indicating that nutsedge competed with itself for light as the initial tuber population was increased. During pepper fruit development and after fruit harvest, nutsedge shoot heights were taller than during pepper flowering but not differentially influenced by nutsedge plant density. Nutsedge shoot number, however, increased linearly with an increase in initial nutsedge density from 30 to 120 plants$\cdot$m^{-2} during pepper fruit development and after fruit harvest. At pepper fruit harvest time, nutsedge shoot heights were only slightly taller than those during pepper fruit development due to the tendency for nutsedge leaf blades to lay over as they lengthened.

Nutsedge plant density did not differentially influence nutsedge shoot height during pepper flowering in fall 1999 (Table 1-50), but shoot number increased linearly from 58 to 68 shoots$\cdot$0.1m^{-2} with an increase in initial nutsedge plant density from 10 to 90 plants$\cdot$m^{-2}. Nutsedge shoot height and number during pepper fruit development

responded similarly to increases in nutsedge density as during pepper flowering. At fruit harvest, nutsedge shoot heights increased quadratically with increases in planted nutsedge density, but changes in height with increasing nutsedge density were slight. Shoot numbers at pepper fruit harvest time increased linearly with increases in nutsedge density.

At pepper flowering in 2000, season interacted with initial nutsedge density on nutsedge shoot height and number (Tables 1-51 and 1-52) primarily because shoot heights and numbers were greater in fall than spring (Table 1-52). During pepper fruit development in 2000, nutsedge shoot height responded quadratically to increases in nutsedge density, but changes in height were small (Table 1-51). Shoot number at this time increased linearly from 90 to 117 shoots·$0.1m^{-2}$ with an increase in planted nutsedge density from 15 to 90 plants·m^{-2}. At harvest time in 2000, shoot height was not differentially influenced by increases in nutsedge density, and shoot number increased linearly from 75 to 101 shoots·0.1 m^{-2} with an increase in initial nutsedge density from 15 to 90 plants·m^{-2}.

Yellow nutsedge leaves are typically 20 to 90 cm long (Wills, 1987). In the present work, leaf blade height and not length was measured. However, a leaf blade length of 90 cm was in agreement with nutsedge leaf blade heights of up to 70 cm observed in these studies. Nutsedge leaf blade heights were consistently taller than pepper plants which were tallest in spring 1999 and did not exceed 56 cm.

Nutsedge leaf blade heights remained similar or decreased with time from fruit development to harvest time each season. This was due to the tendency for nutsedge leaf blades to lay over as they lengthen. The observation that nutsedge shoot counts decreased with time in fall 1999 (Table 1-50) and fall 2000 (Table 1-51) but not in spring seasons

indicated that nutsedge growth was sensitive to photoperiod. According to Jansen (1971), yellow nutsedge vegetative growth is favored by long days characteristic of those in the spring. As daylength decreases in the fall, flowering and tuber formation dominate over vegetative growth (Jansen, 1971; Williams, 1982).

Morales-Payan (1999) reported the development of about 700 yellow nutsedge shoots$\cdot$m^{-2} from 90 to 120 planted tubers$\cdot$m^{-2} at 13 weeks after tomato transplanting in fall 1995 and spring 1996. In spring 1999 in the present study, yellow nutsedge shoot numbers at 13 WAT were about four times greater (2870 shoots$\cdot$m^{-2}) with 120 tubers$\cdot$m^{-2} than numbers reported by Morales-Payan. End-of-season yellow nutsedge shoot numbers in the present study during fall 1999 were less than while those in spring and fall of 2000 were 31% greater than those reported by Morales-Payan (1999). In most seasons, therefore, yellow nutsedge was more prolific when grown with bell pepper than tomato. This was likely due to larger size of tomato than pepper plants. With 90 tubers$\cdot$m^{-2}, end-of-season pepper plant dry weights (Tables 1-29, 1-30, and 1-31) were much less than tomato plant dry weights reported by Morales-Payan (1999).

<u>Nutsedge N Concentration and Uptake</u>

Main effects of treatments on nutsedge shoot N concentration and uptake in spring 1999, fall 1999, and in 2000 are shown in Tables 1-53, 1-54, and 1-55, respectively. In spring and fall 1999, in-row pepper spacing had no effect on nutsedge shoot N concentration and uptake (Tables 1-53 and 1-54).

In 2000, N concentrations in shoots at pepper flowering were higher in spring than fall, but fall-season nutsedge shoots accumulated 30% more N than those in the fall (Table 1-55). As nutsedge shoot N concentration in the fall was only 1.4%, nutsedge

efficiently utilized N. Later in the season, at pepper fruit development, nutsedge concentrations were similar between seasons and spring-planted nutsedge accumulated more N than fall-planted nutsedge. At fruit harvest, nutsedge shoots had accumulated more N in spring than fall. This was further evidence of the decline in nutsedge vigor over time in fall seasons.

In-row pepper spacing in 2000 did not influence yellow nutsedge shoot N concentration and uptake (Table 1-55). Thus, an increase in pepper plant population by spacing plants 23 compared to 31 cm apart did not reduce nutsedge shoot N concentration or uptake.

In spring 1999, N concentration in nutsedge shoots sampled during pepper flowering declined linearly from 2.65% to 2.37% with an increase in initial nutsedge density from 30 to 120 plants$\cdot$m^{-2} (Table 1-53). This was possibly a result of increased intraspecific nutsedge competition with increases in nutsedge density. Nutsedge shoot N concentration and uptake at pepper fruit development did not respond differentially to increases in nutsedge density. At pepper fruit harvest time, however, nutsedge shoot N concentration declined linearly from 1.25% to 1.04% while shoot N uptake increased quadratically with an increase in initial nutsedge density from 30 to 120 plants$\cdot$m^{-2}.

At each sampling time in fall 1999, nutsedge shoot N concentration decreased linearly or quadratically while N uptake did not change with an increase in initial nutsedge density from 10 to 90 plants$\cdot$m^{-2} (Table 1-54). In fall 1999, yellow nutsedge leaves turned yellow by the end of the season, a result of a late planting date. This observation was in agreement with nutsedge shoot N concentrations of below 1% at pepper harvest time.

Nitrogen concentration in nutsedge shoots at pepper flowering in 2000 decreased linearly from 1.99% to 1.72% while N uptake increased linearly from 39 to 75 $kg{\cdot}ha^{-1}$ with an increase in initital nutsedge density from 15 to 90 $plants{\cdot}m^{-2}$ (Table 1-55). Nutsedge shoot N concentrations at pepper fruit development were not influenced by nutsedge density, but accumulation of N by nutsedge shoots increased linearly from 82 to 124 $kg{\cdot}ha^{-1}$ with an increase in nutsedge density from 15 to 90 $plants{\cdot}m^{-2}$.

Season interacted with initial nutsedge density in 2000 on N concentration in nutsedge shoots at pepper fruit harvest time (Tables 1-55 and 1-52). In spring, nutsedge shoot concentrations were constant at 0.71% to 0.76% with increases in nutsedge density, whereas nutsedge shoot N concentration in fall increased linearly from 0.61% to 0.76% with an increase in initial nutsedge density from 15 to 90 $plants{\cdot}m^{-2}$. As nutsedge shoots in spring and fall 2000 were mostly green at harvest time, and shoot N concentrations were below 1%, nutsedge appeared to be an efficient user of N. Nutsedge shoot N uptake at the end of the season increased linearly from 35 to 53 $kg{\cdot}ha^{-1}$ as nutsedge density was increased from 15 to 90 $plants{\cdot}m^{-2}$ (Table 1-55).

Morales-Payan (1999) found that yellow nutsedge accumulated 151 kg·ha-1 of N at the 13th week of interference with tomato with an initial density of 100 $plants{\cdot}m^{-2}$. This amount of N was similar to (Table 1-53) or greater than (Tables 1-54 and 1-55) the amount of N taken up by yellow nutsedge at the end of the season in the present study with 90 nutsedge $plants{\cdot}m^{-2}$.

During each season, especially during pepper flowering time, nutsedge shoots accumulated more N than pepper plants. Furthermore, nutsedge shoot N accumulation increased while pepper N accumulation decreased with increases in planted nutsedge

density. This did not necessarily mean, however, that the main resource being competed for was N. Competition for another common resource could have reduced pepper plant size and dry weight, thereby reducing N accumulation.

Nutsedge Shading of Pepper in 2000

Season and in-row pepper spacing effects on interception of light by nutsedge were contained in interactions as shown in Table 1-56. At pepper flowering, initial nutsedge density interacted with season on nutsedge shading of pepper (Tables 1-56; Fig. 1-10). Slopes generated by regression analysis appeared linear (Fig. 1-10). During each season, the percentage of available light blocked by nutsedge leaf blades increased with an increase in nutsedge density from 15 to 90 plants$\cdot$m^{-2}, but the magnitude of light intercepted by nutsedge was much greater in fall than spring. In spring, nutsedge intercepted about 10% to 40% of available light, whereas, in fall, nutsedge intercepted 50% to 85% of available light.

Although season and initial nutsedge density interacted in their effects on nutsedge shading of bell pepper, season did not interact with nutsedge density on pepper fruit yield loss in 2000 (Table 1-6). It is likely, therefore, that even with less shading of pepper by nutsedge at flowering time in spring than fall, spring-grown pepper was shaded sufficiently to substantially reduce pepper fruit yield.

At pepper flowering, initial nutsedge density also interacted with pepper spacing on nutsedge shading of pepper (Table 1-56; Fig. 1-10; Table 1-57). The percentage of available light intercepted by nutsedge increased at a slightly more rapid rate with pepper plants spaced 23 than 31 cm apart within rows (Fig 1-10). Coefficients of determination

(r^2 values) for these slopes were low, but nutsedge leaf blades intercepted as much as 55% of the available light with both pepper spacings.

At pepper fruit development, the effect of initial nutsedge density on nutsedge shading of pepper varied with season and pepper spacing (Table 1-56; Fig. 1-11; Table 1-57). Within each season, the rate of increase in nutsedge light interception with increases in planted nutsedge density differed with in-row pepper plant spacing. However, there was a more noticeable difference in the magnitude of light intercepted by nutsedge in spring compared to fall. In spring, nutsedge leaves intercepted between 40% and 60% of available light with nutsedge densities between 45 and 90 plants$\cdot$m^{-2}. With the same nutsedge densities, fall-grown nutsedge shoots intercepted nearly 80% of available light.

As nutsedge shoots grew taller than pepper plants and significantly shaded pepper plants, it appeared that nutsedge and pepper plants were primarily competing for light. This conclusion was further evidenced by the tendency for spring-grown pepper plants in 1999 to grow taller when subjected to nutsedge interference than when grown weed-free (Table 1-6). In fall 1999, pepper plants were less competitive than in spring 1999 and, hence, did not increase in height with increases in initial nutsedge plant density (Table 1-7). Although nutsedge may have also competed with pepper for N, evidence for this was not as conclusive as evidence suggesting that nutsedge competed strongly with pepper for light. The apparent sensitivity of pepper to shading was in agreement with other reports where shading reduced pepper flower number and subsequent fruit yield (Jeon and Chung, 1982; Shifriss et al., 1994).

Table 1-1. Dates during each season in 1999 and 2000 for planting and events at pepper flowering, fruit development, and at or nearly at fruit harvest.

	1999		2000	
	Spring	Fall	Spring	Fall
Planted pepper	24 March	2 Sept.	23 March	16 Aug.
Planted nutsedge	24-25 March	30 Aug.	22 March	16-17 Aug.
	At late pepper flowering			
Pepper ht measured^{z}	3 May	12 Oct.	4 May	26 Sept.
Nutsedge shoots counted and sampled	data not obtained	12 Oct.	4 May	26 Sept.
	At pepper fruit development			
Plant ht measured^{z}	2 June	1 Nov.	30 May	18 Oct.
Nutsedge shoots counted and sampled	2 June	2 Nov.	30 May	17 Oct.
	At first and second pepper fruit harvest			
1st: Fruit no. and wt. recorded	16 June	22 Nov.	9 June	6 Nov.
2nd: Fruit no. and wt. recorded	25 June	---	25 June	15 Nov.
	Nearly at or after final pepper fruit harvest			
Plant ht measured^{z}	24 June	23 Nov.	28 June	15 Nov.
Nutsedge shoots counted and sampled	24 June	24 Nov.	28-29 June	20 Nov.
Pepper plants sampled	30 June	29 Nov.	26-27 June	15 Nov.

^{z}Pepper plant and nutsedge shoot heights were obtained.

Table 1-2. Main effects of in row bell pepper plant spacing and initial yellow nutsedge tuber density on large, marketable, and total pepper fruit weight in spring 1999.

	Pepper fruit yield ($t \cdot ha^{-1}$ and % loss)					
	Large		Marketable		Total	
Treatment	$t \cdot ha^{-1}$	% loss^{Z}	$t \cdot ha^{-1}$	% loss	$t \cdot ha^{-1}$	% loss
Pepper spacing (cm)						
23	20.89	64	25.60	62	27.58	65
31	17.93	72	22.47	72	24.74	73
Signif.	**	**	**	***	**	***
Tuber density (TD; $no \cdot m^{-2}$)						
0	42.59	-	51.92	-	58.85	-
30	19.05	55	24.14	54	25.23	57
60	14.49	66	18.00	65	18.98	68
90	12.63	70	15.78	69	16.65	71
120	8.28	80	10.33	80	11.09	81
0 vs. nutsedge	***	-	***	-	***	-
TD (30 to 120)	L***	-	L***	-	L***	-

^{Z}Values were expressed as percent loss relative to those obtained with pepper grown weed-free (0 TD).

$^{NS, **, ***}$Effects were nonsignificant or significant at $P \leq 0.01$ or 0.001, respectively, according to F tests. Competition (TD from 30 to 120) vs. no competition (0 TD) effects were tested with contrasts. Tuber density effects were linear (L) according to polynomial contrasts.

Table 1-3. Main effects of in row bell pepper plant spacing and initial yellow nutsedge tuber density effects on large, marketable, and total pepper fruit weight in fall 1999.

	Pepper fruit yield ($t \cdot ha^{-1}$ and % loss)					
	Large		Marketable		Total	
Treatment	$t \cdot ha^{-1}$	% loss[Z]	$t \cdot ha^{-1}$	% loss[Z]	$t \cdot ha^{-1}$	% loss[Z]
Pepper spacing (cm)						
23	4.66	74	6.20	66	7.04	64
31	4.62	74	6.23	67	6.75	67
Signif.	NS	NS	NS	NS	NS	NS
Tuber density (TD; $no \cdot m^{-2}$)						
0	11.82	-	13.79	-	15.15	-
10	7.73	38	9.58	33	10.21	34
20	5.25	56	7.07	48	7.55	50
30	2.33	84	4.53	69	5.20	67
60	0.51	95	1.50	87	2.15	84
90	0.21	98	0.81	94	1.09	92
0 vs. nutsedge	***	-	***	-	***	-
TD (30 to 120)	Q***	-	Q***	-	Q**	-

[Z]Values were expressed as percent loss relative to those obtained with pepper grown weed-free (0 TD).

[NS, **, ***]Main effects and interactions were nonsignificant or significant at $P \leq 0.01$ or 0.001, respectively, according to F tests. Competition (TD from 10 to 90) vs. no competition (0 TD) effects were tested with contrasts. Effects of nutsedge density were quadratic (Q) according to polynomial contrasts.

Table 1-4. Main effects of season, in-row bell pepper plant spacing, and initial yellow nutsedge tuber density effects on large, marketable, and total pepper fruit weight in spring and fall 2000.

	Pepper fruit yield ($t \cdot ha^{-1}$ and % loss)					
	Large		Marketable		Total	
Treatment	$t \cdot ha^{-1}$	% loss[Z]	$t \cdot ha^{-1}$	% loss	$t \cdot ha^{-1}$	% loss
Season (S)						
Spring	21.38	63	22.55	63	24.71	65
Fall	2.55	91	4.39	88	4.96	86
Signif.		***		***		***
Pepper spacing (PS; cm)						
23	13.66	74	15.17	72	16.67	72
31	12.37	78	13.79	76	15.19	77
Signif.		*	NS	*	*	**
S X PS	**	NS	NS	NS	NS	NS
Tuber density (TD; $no \cdot m^{-2}$)						
0	29.55	-	33.59	-	37.52	-
15	17.03	52	19.00	50	20.64	50
30	10.93	74	12.14	70	13.45	70
45	8.11	81	8.92	79	9.88	79
60	6.88	84	7.29	83	7.92	84
90	5.57	87	5.93	87	6.20	88
TD (15 to 90)		C**		Q***		C*
S X DEN	***	NS	***	NS	***	NS

[Z]Values were expressed as percent loss relative to those obtained with pepper grown weed-free (0 TD).

[NS, *, **, ***]Main effects and interactions were nonsignificant or significant at $P \leq 0.05$, 0.01, 0.001, respectively, according to F tests. Effects of nutsedge density were quadratic (Q) or cubic (C) according to polynomial contrasts.

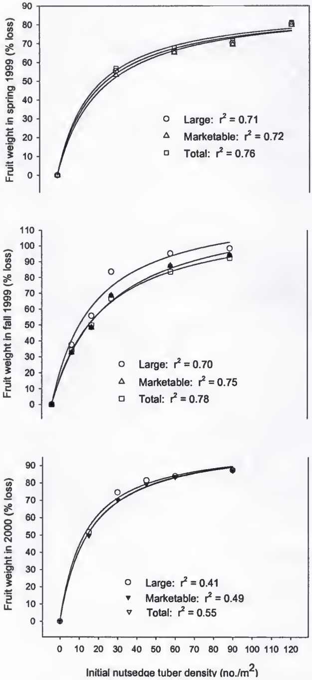


Fig. 1-1. Main effect of initial yellow nutsedge tuber density on large, marketable, or total bell pepper fruit weight in spring 1999, fall 1999, and in 2000 as percent loss relative to that with no nutsedge. Data in spring and fall of 2000 were combined. Coefficients of determination (r^2 values) were determined by regressing data within means (shown).

Table 1-5. Coefficients for the rectangular hyperbola [Cousen's: $Y = ID/(1+ID/A)$] used to characterize the effect of initial yellow nutsedge tuber density on bell pepper fruit weights as percent loss relative to those with no nutsedge.

	Parameter[z]	
Fruit grade	I	A
	Spring 1999	
Large	0.05 ± 0.01	89.53 ± 4.94
Marketable	0.04 ± 0.01	90.82 ± 5.24
Total	0.05 ± 0.01	89.89 ± 4.18
	Fall 1999	
Large	0.05 ± 0.01	126.49 ± 9.48
Marketable	0.04 ± 0.01	126.32 ± 10.10
Total	0.04 ± 0.01	119.06 ± 8.04
	Spring and fall 2000	
Large	0.08 ± 0.02	102.76 ± 6.19
Marketable	0.07 ± 0.01	104.09 ± 5.91
Total	0.06 ± 0.01	104.60 ± 5.28

[z]Coefficients ± standard errors for each variable were obtained with data within means.

Table 1-6. Main effects of in-row bell pepper plant spacing and initial yellow nutsedge tuber density on pepper plant height during pepper flowering, fruit development, and after final fruit harvest in spring 1999.

	Pepper ht at three growth stages (cm)		
Treatment	Flowering[z]	Fruit development	Fruit harvest
Pepper spacing (cm)			
22.9	25.0	51.2	53.2
30.5	25.0	52.0	54.5
Signif.	NS	NS	NS
Tuber density (TD; no.·m^{-2})			
0	22.4	47.9	49.9
30	23.4	51.4	53.1
60	25.6	53.3	55.8
90	26.7	54.2	56.3
120	26.8	51.3	54.1
0 vs. nutsedge	***	**	**
TD (30 to 120)	Q*	NS	NS

[z]Pepper plant height from the bed surface to highest bud was measured during pepper flowering, fruit development, and at fruit harvest at 6, 10, and 14 weeks after pepper transplanting, respectively.

[NS, *, **, ***]Main effects were nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively, according to F tests. Competition (30 to 120 TD) vs. no competition (0 TD) effects were tested with contrasts. The significant tuber density effect was quadratic (Q) according to polynomial contrasts.

Table 1-7. Main effects of in-row bell pepper plant spacing and initial yellow nutsedge tuber density on pepper plant height during pepper flowering, fruit development, and at final fruit harvest in fall 1999.

	Pepper ht at three growth stages (cm)		
Treatment	Flowering[Z]	Fruit development	Fruit harvest
Pepper spacing (cm)			
22.9	29.1	29.7	30.0
30.5	29.2	30.5	30.4
Signif.	NS	NS	NS
Tuber density (TD; no.·m^{-2})			
0	31.4	33.0	32.0
10	32.7	33.9	33.6
20	31.2	31.9	31.3
30	30.8	30.9	31.6
60	24.7	25.8	26.2
90	24.2	25.3	26.3
0 vs. nutsedge	*	*	X
TD (10 to 90)	L***	L***	L***

[Z]Pepper plant height from the bed surface to highest bud was measured during pepper flowering, fruit development, and at fruit harvest at 6, 9, and 14 weeks after pepper planting, respectively.

[NS, X, *, ***]Main effects were nonsignificant or significant at $P \leq 0.10$, 0.05, or 0.001, respectively, according to F tests. Competition (30 to 120 TD) vs. no competition (0 TD) effects were tested with contrasts. Significant tuber density effects were linear (L) according to polynomial contrasts.

Table 1-8. Main effects of season, in-row bell pepper plant spacing, and initial yellow nutsedge tuber density on pepper plant height during pepper flowering, fruit development, and after final fruit harvest in spring and fall of 2000.

	Pepper ht at three growth stages (cm)		
Treatment	Flowering[Z]	Fruit development	Fruit harvest
Season			
Spring	25.4	44.8	49.4
Fall	19.4	23.4	26.6
Signif.			***
Pepper spacing (cm)			
22.9	23.0	35.1	38.9
30.5	22.4	35.4	39.6
Signif.	NS	NS	NS
Tuber density (no.·m^{-2})			
0	21.4	35.3	39.4
15	24.0	37.6	40.4
30	22.0	34.7	36.4
45	22.5	35.8	40.4
60	23.5	33.9	38.1
90	22.8	34.4	40.9
0 vs. nutsedge			NS
Nutsedge (15 to 90)			QR**
Season X density[Y]	***	***	NS

[Z]Pepper plant heights were obtained during flowering, fruit development, and after fruit harvest 6, 10, and 14 weeks after pepper transplanting (WAT) in spring and 6, 9, and 14 WAT in fall, respectively.

[Y]Interactions were determined with nutsedge treatments.

[NS,**,***]Main effects and interactions were nonsignificant or significant at $P \leq 0.01$ or 0.001, respectively, according to F tests. Competition (15 to 90 TD) vs. no competition (0 TD) effect at fruit harvest was tested with a contrast. Ttuber density (15 to 90 TD) effect at fruit harvest was quartic (QR) according to a polynomial contrast.

Table 1-9. Interaction of season and initial yellow nutsedge tuber density on pepper plant height during flowering and fruit development in 2000.

	Tuber density (no.·m^{-2})							
Season	0	15	30	45	60	90	0 vs nutsedge	Signif.[Z]
	Ht at flowering (cm)							
Spring	23	24	25	26	27	27	***	L***
Fall	20	24	19	18	19	17	NS	C*
	Ht at fruit development (cm)							
Spring	42	45	44	48	45	46	***	QR**
Fall	27	29	23	21	20	20	*	L***

[Z]Values obtained with pepper grown weed-free (0) were excluded in tests for significance of pepper height response to tuber density.

[NS, *, **, ***]Row effects were nonsignificant or significant at P ≤ 0.05, 0.01, or 0.001 according to F-tests. Competition (15 to 90 tubers·m^{-2}) vs no competition (0 tubers·m^{-2}) effects were tested with contrasts. Significant tuber density (15 to 90 tubers·m^{-2}) were linear (L), cubic (C), or quartic (QR) according to polynomial contrasts.

Table 1-10. Main effects of in-row bell pepper plant spacing and initial yellow nutsedge tuber density on leaf number per pepper plant during fruit development and after final fruit harvest in spring 1999.

	Leaves at two growth stages (no. and % loss)^Z			
	Fruit development^Z		Fruit harvest	
Treatment	no.	% loss^Y	no.	% loss
Pepper spacing (cm)				
22.9	69.4	62.7	62.9	52.7
30.5	72.0	69.5	69.9	58.5
Signif.	NS	*	NS	NS
Tuber density (TD; no.·m^{-2})				
0	151.7	---	122.5	---
30	61.3	58.8	64.3	44.7
60	56.9	62.3	57.1	51.1
90	42.1	71.2	44.1	63.6
120	41.5	72.1	44.3	63.0
0 vs. nutsedge	***	---	***	---
TD (30 to 120)	L***	L***	L***	L**

^{Z}Pepper plants were sampled during fruit development and at fruit harvest at 10 and 14 weeks after pepper transplanting, respectively.

^{Y}Values were expressed as percent loss relative to those obtained with 0 TD.

$^{NS, *, **, ***}$Main effects were nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively, according to F tests. Competition (30 to 120 TD) vs. no competition (0 TD) effects were tested with contrasts. Tuber density effects were linear (L) according to polynomial contrasts.

Table 1-11. Main effects of in-row bell pepper plant spacing and initial yellow nutsedge tuber density on leaf number per pepper plant during pepper flowering, fruit development, and after final fruit harvest in fall 1999.

	Leaves at three growth stages (no. and % loss)					
	Flowering[Z]		Fruit development		Fruit harvest	
Treatment	no.	% loss[Y]	no.	% loss	no.	% loss
Pepper spacing (cm)						
22.9	26	52.8	26	46.0	25	47.4
30.5	28	51.8	29	47.2	28	50.9
Signif.	NS	NS	NS	NS	NS	NS
Tuber density (TD; no.·m^{-2})						
0	49	---	46	---	45	---
10	33	31.3	35	21.9	30	33.3
20	30	39.0	28	36.3	24	46.5
30	23	53.9	23	48.9	19	57.5
60	16	65.3	18	58.8	17	60.0
90	13	71.9	14	67.2	23	48.6
0 vs. nutsedge	***	---	***	---	***	---
TD (10 to 90)	Q*	Q*	Q*	Q*	Q***	Q***

[Z] Pepper plants were sampled during pepper flowering, fruit development, and at fruit harvest at 6, 9, and 13 weeks after pepper transplanting, respectively.

[Y] Values were expressed as percent loss relative to those obtained with 0 TD.

NS, *, **, *** Main effects were nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively, according to F tests. Competition (10 to 90 TD) vs. no competition (0 TD) effects were tested with contrasts. Tuber density effects were quadratic (Q) according to polynomial contrasts.

Table 1-12. Main effects of season, in-row bell pepper plant spacing and initial yellow nutsedge tuber density on leaf number per pepper plant during late flowering, fruit development, and at final fruit harvest in spring and fall 2000.

	Leaves at three growth stages (no. and % loss)					
	Flowering[Z]		Fruit development		Fruit harvest	
Treatment	no.	% loss[Y]	no.	% loss	no.	% loss
Season						
Spring	39	28.7	67	64.8	52	59.6
Fall	16	41.3	21	63.1	21	62.0
Signif.	***	NS	***	NS	***	NS
Pepper spacing (cm)						
22.9	28	34.6	45	59.6	35	56.6
30.5	29	34.0	48	68.6	42	64.7
Signif.	NS	NS	NS	***	***	***
Tuber density (TD; no.$\cdot$m^{-2})						
0	43	---	103	---	79	---
15	35	14.3	56	43.6	42	47.3
30	29	25.8	40	60.1	32	59.2
45	25	38.8	31	69.2	29	61.7
60	23	42.8	27	72.4	23	69.0
90	19	49.9	24	75.0	25	66.9
0 vs. nutsedge	***	---	***	---	***	---
TD (15 to 90)	Q*	L***	Q***	Q***	Q***	Q***

[Z]Pepper plants sampled during pepper flowering, fruit development, and after fruit harvest at 6, 10, and 14 or 6, 9, and 14 weeks after pepper transplanting in spring and fall, respectively

[Y]Values were expressed as percent loss relative to those obtained with 0 TD.

[NS, *, **, ***]Main effects were nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively, according to F tests. Competition (15 to 90 TD) vs no competition (0 TD) effects were tested with contrasts. Tuber density effects were linear (L) or quadratic (Q) according to polynomial contrasts.

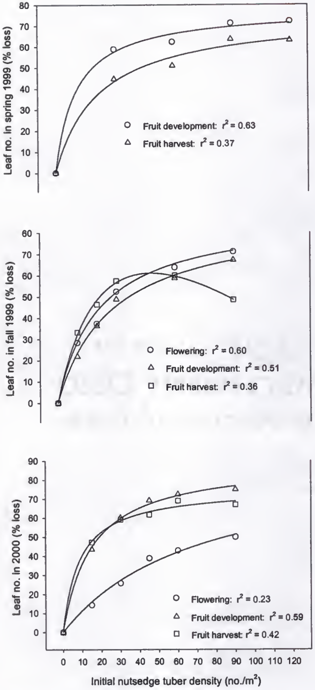


Fig. 1-2. Main effect of initial yellow nutsedge tuber density on loss of leaf number, relative to that with no nutsedge, in spring 1999, fall 1999, and in 2000. Data in spring and fall of 2000 were combined. Coefficients of determination (r^2 values) were determined by regressing data within means (shown).

Table 1-13. Coefficients for the rectangular hyperbola [$Y = A \times X/(B + X)$] used to characterize the effect of initial yellow nutsedge tuber density leaf number per pepper plant as percent loss relative to that with no nutsedge.

	Parameter[Z]	
Pepper growth	A	B
	Spring 1999	
Fruit development	77.7 ± 4.0	10.6 ± 4.0
Fruit harvest	75.3 ± 9.0	22.1 ± 10.5
	Fall 1999	
Flowering	88.2 ± 7.8	20.8 ± 5.3
Fruit development	87.5 ± 11.5	27.3 ± 9.3
Fruit harvest	---[Y]	---
	Spring and fall 2000	
Flowering	91.2 ± 32.7	70.0 ± 45.3
Fruit development	89.6 ± 4.1	15.0 ± 2.6
Fruit harvest	75.4 ± 3.3	8.6 ± 2.0

[Z]Coefficients ± standard errors for each variable were obtained with data within means. Models were significant at $P \leq 0.001$.

[Y]This equation was $168.5 \pm 90.0 \times X/ (31.6 \pm 20.0 + X) - 0.84 \pm 0.6 (X)$. "x" = multiply sign

Table 1-14. Main effects of in-row bell pepper plant spacing and initial yellow nutsedge tuber density on leaf area per pepper plant during pepper flowering, fruit development, and after final fruit harvest in spring 1999.

	Leaf area at three growth stages (cm^2 and % loss)					
	Flowering[Z]		Fruit development		Fruit harvest	
Treatment	cm^2	% loss[Y]	cm^2	% loss	cm^2	% loss
Pepper spacing (cm)						
22.9	893	33.8	2043	61.4	1488	52.5
30.5	961	43.0	2141	68.1	1750	59.0
Signif.	NS	NS	NS	NS	*	NS
Tuber density (TD; no.·m^{-2})						
0	1356	---	4392	---	3006	---
30	1006	24.3	1761	59.2	1543	45.1
60	867	34.5	1737	60.0	1440	49.7
90	800	39.6	1205	71.7	1124	61.6
120	603	55.2	1369	68.2	982	66.7
0 vs. nutsedge	***	---	***	---	***	---
TD (30 to 120)	L***	L***	C*	L*	L***	L**

[Z]Pepper plants were sampled during pepper flowering, fruit development, and after final fruit harvest at 6, 10, and 14 weeks after pepper planting, respectively.

[Y]Values were expressed as percent loss relative to those obtained with 0 TD.

[NS, *, **, ***]Main effects were nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively, according to F tests. Competition (30 to 120 TD) vs. no competition (0 TD) effects were tested with contrasts. Tuber density effects were linear (L) or cubic (C) according to polynomial contrasts.

Table 1-15. Main effects of in-row bell pepper plant spacing and initial yellow nutsedge tuber density on leaf area per pepper plant during pepper flowering, fruit development, and after fruit harvest in fall 1999.

	Leaf area at three growth stages (cm^2 and % loss)					
	Flowering[Z]		Fruit development		Fruit harvest	
Treatment	cm^2	% loss[Y]	cm^2	% loss	cm^2	% loss
Pepper spacing (cm)						
22.9	532	51.1	527	41.4	518	45.3
30.5	555	43.8	551	43.9	543	49.0
Signif.	NS	NS	NS	NS	NS	NS
Tuber density (TD; $no.\cdot m^{-2}$)						
0	914	---	872	---	902	---
10	686	22.2	721	14.3	619	29.2
20	616	33.3	554	29.2	517	41.1
30	457	50.7	466	45.8	426	52.2
60	347	60.2	315	62.1	352	56.4
90	242	70.8	306	61.8	366	57.1
0 vs. nutsedge	***	---	***	---	***	---
TD (10 to 90)	L***	L***	Q**	Q**	Q**	L**

[Z]Pepper plants were sampled during pepper flowering, fruit development, and after fruit harvest at 6, 9, and 14 weeks after pepper transplanting, respectively.

[Y]Values were expressed as percent loss relative to those obtained with 0 TD.

[NS, *, **, ***]Main effects were nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively, according to F tests. Competition (10 to 90 TD) vs. no competition (0 TD) effects were tested with contrasts. Tuber density effects were linear (L) or quadratic (Q) according to polynomial contrasts.

Table 1-16. Main effects of season, in-row bell pepper plant spacing and initial yellow nutsedge tuber density on leaf area per pepper plant during pepper flowering, fruit development, and after final fruit harvest in spring and fall of 2000.

	Leaf area at three growth stages (cm^2 and % loss)					
	Flowering[Z]		Fruit development		Fruit harvest	
Treatment	cm^2	% loss[Y]	cm^2	% loss	cm^2	% loss
Season						
Spring	630	30.7	1568	60.2	904	57.5
Fall	219	38.1	335	64.2	353	57.1
Signif.	***	NS	***	NS	***	NS
Pepper spacing (cm)						
22.9	444	36.8	959	60.1	606	54.1
30.5	451	31.2	1081	63.9	712	60.4
Signif.	NS	NS	*	NS	**	NS
Tuber density (TD; $no.\cdot m^{-2}$)						
0	673	---	2102	---	1324	---
15	557	10.7	1238	40.3	751	39.4
30	461	25.0	864	59.7	562	54.9
45	347	41.8	710	68.4	494	60.4
60	352	42.5	644	67.5	412	65.4
90	294	49.8	563	74.0	413	66.3
0 vs. nutsedge	***	---	***	---	***	---
TD (15 to 90)	Q***	L***	Q***	C**	Q***	Q**

[Z]Leaf area was recorded for pepper plants sampled during flowering, fruit development, and after final fruit harvest at 6, 10, and 14 or 6, 9, and 14 weeks after pepper transplanting in spring and fall, respectively.

[Y]Values were expressed as percent loss relative to those obtained with 0 TD.

[NS, *, **, ***]Main effects were nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively, according to F tests. Competition (15 to 90 TD) vs. no competition (0 TD) effects were tested with contrasts. Tuber density effects were linear (L), quadratic (Q), or cubic (C) according to polynomial contrasts.

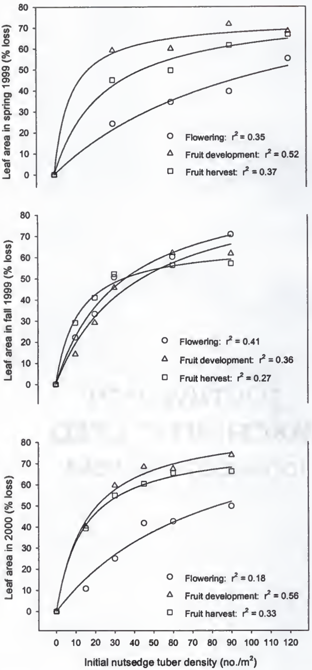


Fig. 1-3. Main effect of initial yellow nutsedge tuber density on loss of bell pepper plant leaf area, relative to that with no nutsedge, in spring 1999, fall 1999, and in 2000. Data in spring and fall of 2000 were combined. Coefficients of determination (r^2 values) were determined by regressing data within means (shown).

Table 1-17. Coefficients for the rectangular hyperbola [$Y = A \times X/(B + X)$] used to characterize the effect of initial yellow nutsedge tuber density on leaf area per pepper plant as percent loss relative to that with no nutsedge.

	Parameter[z]	
Pepper growth stage	A	B
	Spring 1999	
Flowering	97.9 ± 37.6	8.3 ± 73.8
Fruit development	73.7 ± 4.4	8.3 ± 3.9
Fruit harvest	78.5 ± 10.1	25.8 ± 12.0
	Fall 1999	
Flowering	96.0 ± 17.9	36.6 ± 14.6
Fruit development	95.5 ± 24.2	39.9 ± 22.4
Fruit harvest	66.8 ± 8.4	11.6 ± 5.5
	Spring and fall 2000	
Flowering	98.5 ± 49.6	80.1 ± 69.7
Fruit development	88.2 ± 4.6	16.0 ± 3.0
Fruit harvest	78.8 ± 5.9	14.0 ± 4.1

[z]Coefficients ± standard errors for each variable were obtained with data within means. Models were significant at $P \leq 0.001$.

Table 1-18. Main effects of in-row bell pepper plant spacing and initial yellow nutsedge tuber density on leaf dry weight per pepper plant during pepper flowering, fruit development, and after final fruit harvest in spring 1999.

	Leaf dry wt at three growth stages (g and % loss)					
	Flowering[Z]		Fruit development		Fruit harvest	
Treatment	g	% loss[Y]	g	% loss	g	loss
Pepper spacing (cm)						
22.9	4.30	37.86	10.14	61.12	8.83	52.95
30.5	4.67	46.77	10.72	66.16	10.66	57.55
Signif.	NS	NS	NS	NS	*	NS
Tuber density (TD; no.$\cdot$m^{-2})						
0	6.89	---	21.47	---	18.01	---
30	4.99	26.55	8.83	58.04	8.64	48.20
60	4.06	39.51	8.81	58.84	8.95	47.77
90	3.80	42.92	6.07	70.76	6.79	61.16
120	2.70	60.27	7.00	66.92	6.33	63.88
0 vs. nutsedge	***	---	***	---	***	---
TD (30 to 120)	L***	L***	C*	L**	L**	L*

[Z]Pepper plants were sampled during pepper flowering, fruit development, and after final fruit harvest 6, 10, and 14 weeks after pepper planting.

[Y]Values were expressed as percent loss relative to those obtained with 0 TD.

[NS, *, **, ***]Main effects were nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively, according to F tests. Competition (30 to 120 TD) vs. no competition (0 TD) effects were tested with contrasts. Tuber density effects were linear (L) or cubic (C) according to polynomial contrasts.

Table 1-19. Main effects of in-row bell pepper plant spacing and initial yellow nutsedge tuber density on leaf dry weight per pepper plant during pepper flowering, fruit development, and after fruit harvest in fall 1999.

	Leaf dry wt at three growth stages (g and % loss)					
	Flowering[Z]		Fruit development		Fruit harvest	
Treatment	g	% loss[Y]	g	% loss	g	% loss
Pepper spacing (cm)						
22.9	2.31	58.4	2.49	46.2	3.20	48.0
30.5	2.53	61.9	2.64	49.2	3.58	54.5
Signif.	NS	NS	NS	NS	NS	NS
Tuber density (TD; no.$\cdot$m^{-2})						
0	4.88	---	4.43	---	6.11	---
10	3.18	33.5	3.48	18.2	3.98	33.1
20	2.50	49.3	2.56	35.9	3.39	43.2
30	1.81	62.9	2.13	50.9	2.67	55.2
60	1.30	72.4	1.37	67.6	2.14	61.0
90	0.85	82.6	1.41	65.8	2.07	63.7
0 vs. nutsedge	***	---	***	---	***	---
TD (10 to 90)	Q*	Q**	Q**	Q**	Q**	L***

[Z]Pepper plants were sampled during pepper flowering, fruit development, and after fruit harvest 6, 9, and 13 weeks after pepper planting.

[Y]Values were expressed as percent loss relative to those obtained with 0 TD.

[NS, *, **, ***]Main effects were nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively, according to F tests. Competition (10 to 90 TD) vs. no competition (0 TD) effects were tested with contrasts. Tuber density effects were linear (L) or quadratic (Q) according to polynomial contrasts.

Table 1-20. Main effects of season, in-row bell pepper plant spacing and initial yellow nutsedge tuber density on leaf dry weight per pepper plant during bell pepper flowering, fruit development, and after final fruit harvest in spring and fall 2000.

	Leaf dry wt at three growth stages (g and % loss)					
	Flowering[Z]		Fruit development		Fruit harvest	
Treatment	g	% loss[Y]	g	% loss	g	% loss
Season						
Spring	3.54	34.0	7.78	62.0	5.06	59.6
Fall	1.04	50.6	1.76	72.1	1.84	70.4
Signif.	***	X	***	**	***	X
Pepper spacing (cm)						
22.9	2.39	43.8	4.72	64.3	3.35	61.8
30.5	2.47	38.9	5.49	68.6	3.90	67.7
Signif.	NS	NS	**	*	*	X
Tuber density (TD; no.$\cdot$m^{-2})						
0	3.83	---	11.02	---	7.90	---
15	3.08	16.5	6.18	45.0	3.91	47.6
30	2.45	30.1	4.24	64.2	2.86	64.1
45	1.93	47.5	3.47	71.4	2.69	66.9
60	1.81	52.0	3.04	74.5	2.17	72.0
90	1.48	60.7	2.67	77.3	2.24	71.6
0 vs. nutsedge	***	---	***	---	***	---
TD (15 to 90)	Q***	Q*	Q***	C*	Q***	Q***

[Z]Pepper plants were sampled during pepper flowering, fruit development, and after final fruit harvest 6, 10, and 14 or 6, 9, and 14 weeks after pepper transplanting in spring and fall, respectively

[Y]Values were expressed as percent loss relative to those obtained with 0 TD.

[NS, X, *, **, ***]Main effects were nonsignificant or significant at P $\leq$ 0.1, 0.05, 0.01, or 0.001, respectively, according to F tests. Competition (15 to 90 TD) vs. no competition (0 TD) effects were tested with contrasts. Tuber density effects were quadratic (Q) or cubic (C) according to polynomial contrasts.

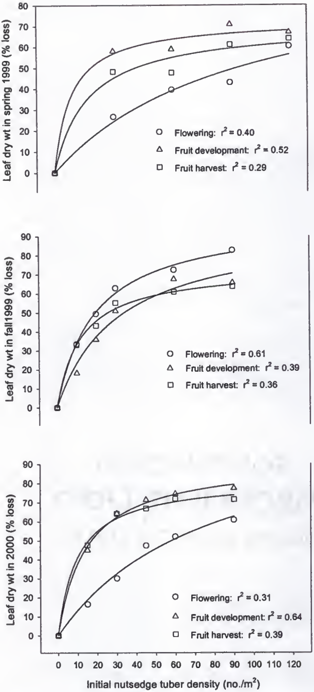


Fig. 1-4. Main effect of initial yellow nutsedge tuber density on leaf dry weight per bell pepper plant in spring 1999, fall 1999, and in 2000 as percent loss relative to that with no nutsedge. Data in spring and fall of 2000 were combined. Coefficients of determination (r^2 values) were determined by regressing data within means (shown).

Table 1-21. Coefficients for the rectangular hyperbola [$Y = A \times X/(B + X)$] used to characterize the effect of initial yellow nutsedge tuber density on loss of bell pepper leaf dry weight.

	Parameter[Z]	
Pepper growth stage	A	B
	Spring 1999	
Flowering	100.8 ± 33.5	95.0 ± 59.4
Fruit development	72.6 ± 4.4	8.42 ± 4.0
Fruit harvest	70.4 ± 8.9	17.0 ± 10.1
	Fall 1999	
Flowering	98.9 ± 8.5	19.2 ± 4.7
Fruit development	94.8 ± 18.6	30.9 ± 14.9
Fruit harvest	73.3 ± 7.6	12.2 ± 4.6
	Spring and fall 2000	
Flowering	116.3 ± 37.3	77.0 ± 43.1
Fruit development	91.8 ± 3.6	14.2 ± 2.2
Fruit harvest	81.9 ± 4.2	9.9 ± 2.5

[Z]Coefficients ± standard errors for each variable were obtained with data within means. Models were significant at $P \leq 0.001$.

Table 1-22. Main effects of in-row bell pepper plant spacing and initial yellow nutsedge tuber density on stem dry weight per pepper plant during pepper flowering, fruit development, and after final fruit harvest in spring 1999.

	Stem dry wt at three growth stages (g and % loss)					
	Flowering[Z]		Fruit development		Fruit harvest	
Treatment	g	% loss[Y]	g	% loss	g	% loss
Pepper spacing (cm)						
22.9	2.76	14.7	10.54	56.4	16.69	49.0
30.5	2.78	27.7	10.94	55.9	18.65	53.4
Signif.	NS	*	NS	NS	*	NS
Tuber density (TD; no.$\cdot$m^{-2})						
0	3.36	---	19.65	---	30.60	---
30	3.10	7.4	9.02	53.6	15.45	47.0
60	2.66	20.3	9.90	49.3	16.64	43.9
90	2.62	20.8	7.26	61.7	13.43	55.1
120	2.12	36.3	7.88	60.0	12.26	58.9
0 vs. nutsedge	***	---	***	---	***	---
TD (30 to 120)	L***	L***	C*	C*	L**	L**

[Z]Pepper plants were sampled during pepper flowering, fruit development, and after final fruit harvest at 6, 10, and 14 weeks after pepper planting.

[Y]Values were expressed as percent loss relative to those obtained with 0 TD.

[NS, *, **, ***]Effects were nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively, according to F tests. Competition (30 to 120 TD) vs. no competition (0 TD) effects were tested with contrasts. Tuber density effects were linear (L) or cubic (C) according to polynomial contrasts.

Table 1-23. Main effects of in-row bell pepper plant spacing and initial yellow nutsedge tuber density on stem dry weight per pepper plant during pepper flowering, fruit development, and after fruit harvest in fall 1999.

	Stem dry wt at three growth stages (g and % loss)					
	Flowering[Z]		Fruit development		Fruit harvest	
Treatment	g	% loss[Y]	g	% loss	g	% loss
Pepper spacing (cm)						
22.9	2.34	60.2	3.00	45.8	3.70	57.9
30.5	2.50	62.7	3.18	51.7	4.01	64.0
Signif.	NS	NS	NS	NS	NS	NS
Tuber density (TD; no.$\cdot$m^{-2})						
0	5.02	---	5.38	---	7.95	---
10	3.27	33.4	4.19	18.9	4.73	39.5
20	2.37	52.4	3.15	37.8	3.59	54.6
30	1.83	63.3	2.61	49.6	2.82	64.6
60	1.26	74.2	1.61	68.8	2.02	72.3
90	0.80	83.9	1.60	68.4	2.00	73.7
0 vs. nutsedge	***	---	***	---	***	---
TD (10 to 90)	Q**	Q*	Q***	Q**	Q**	Q**

[Z]Pepper plants were sampled during pepper flowering, fruit development, and at fruit harvest at 6, 9, and 13 weeks after pepper planting.

[Y]Values were expressed as percent loss relative to those obtained with 0 TD.

[NS, *, **, ***]Effects were nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively, according to F tests. Competition (TD from 10 to 90) vs. no competition (0) effects were tested with contrasts. Tuber density effects were quadratic (Q) according to polynomial contrasts.

Table 1-24. Main effects of season, in-row bell pepper spacing and initial yellow nutsedge tuber density on stem dry weight per pepper plant during pepper flowering, fruit development, and after final fruit harvest in spring and fall 2000.

	Stem dry wt at three growth stages (g and % loss)					
	Flowering[Z]		Fruit development		Fruit harvest	
Treatment	g	% loss[Y]	g	% loss	g	% loss
Season						
Spring	2.29	22.4	8.70	52.0	11.22	49.3
Fall	0.90	46.6	1.60	69.1	2.43	69.6
Signif.	***	**	***	***	***	**
Pepper spacing (cm)						
22.9	1.70	36.9	5.21	57.3	6.95	57.7
30.5	1.65	29.4	5.87	61.9	7.67	58.9
Signif.	NS	NS	*	NS	NS	NS
Tuber density (TD; no.·m^{-2})						
0	2.39	---	10.37	---	13.82	---
15	1.97	12.1	6.66	36.6	8.32	40.8
30	1.77	20.5	4.93	56.6	6.26	57.6
45	1.38	39.6	4.29	64.5	5.69	61.7
60	1.30	45.0	3.63	68.8	4.87	66.3
90	1.23	48.7	3.38	71.3	4.91	65.2
0 vs. nutsedge	***	---	***	---	***	---
TD (15 to 90)	Q**	Q*	Q***	Q***	Q***	Q***

[Z]Pepper plants sampled during flowering, fruit deveolopment, and after final fruit harvest at 6, 10, and 14 or 6, 9, and 14 weeks after pepper transplanting in spring and fall, respectively

[Y]Values were expressed as percent loss relative to those obtained with 0 TD.

[NS, *, **, ***]Main effects were nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively, according to F tests. Competition (15 to 90 TD) vs. no competition (0 TD) effects were tested with contrasts. Tuber density effects were quadratic (Q) according to polynomial contrasts.

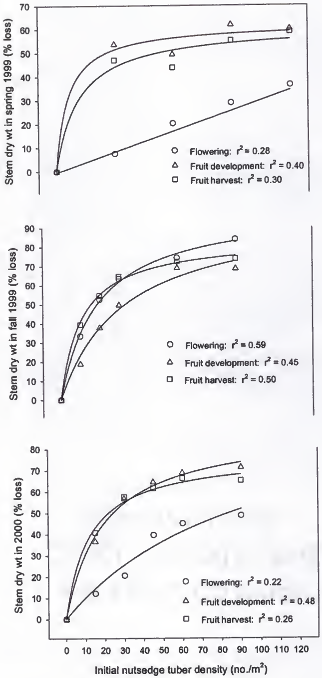


Fig. 1-5. Main effect of initial yellow nutsedge tuber density on stem dry weight per bell pepper plant in spring 1999, fall 1999, and in 2000 as percent loss relative to that with no nutsedge, Data in spring and fall of 2000 were combined. Coefficients of determination (r^2 values) were determined by regressing data within means (shown).

Table 1-25. Coefficients for the rectangular hyperbola [$Y = A \times X/(B + X)$] used to characterize the effect of initial yellow nutsedge tuber density on loss of bell pepper stem dry weight.

	Parameter[Z]	
Pepper growth stage	A	B
	Spring 1999	
Flowering	---[Y]	---
Fruit development	62.1 ± 4.5	6.3 ± 4.4
Fruit harvest	61.2 ± 86.4	11.8 ± 7.5
	Fall 1999	
Flowering	100.5 ± 8.5	18.9 ± 4.8
Fruit development	98.4 ± 17.1	32.1 ± 13.5
Fruit harvest	84.4 ± 6.1	10.7 ± 3.0
	Spring and fall 2000	
Flowering	106.5 ± 54.5	94.7 ± 79.0
Fruit development	89.3 ± 16.2	19.1 ± 4.4
Fruit harvest	77.1 ± 6.1	11.9 ± 4.0

[Z]Coefficients ± standard errors for each variable were obtained with data within means. Models were significant at $P \leq 0.001$.

[Y]At flowering in spring 1999, the equation was linear : $-0.53 \pm 6.0 + 0.29 \pm 0.07$ (X).

Table 1-26. Main effects of in-row pepper spacing and initial yellow nutsedge tuber density on pepper plant fruit weight during pepper fruit development 10 and 9 weeks after pepper transplanting in spring 1999 and fall 1999, respectively.

	Spring 1999		Fall 1999	
	Fruit dry wt per plant		Fruit dry wt per plant	
Treatment	g	loss (%)[z]	g	loss (%)
Pepper spacing				
22.9	14.7	66.0	4.29	58.7
30.5	15.0	74.9	4.34	65.0
Signif.	NS	*	NS	NS
Tuber density (TD; no.$\cdot$m^{-2})				
0	34.4	---	9.41	---
10	---	---	5.75	33.1
20	---	---	4.60	45.6
30	14.1	57.5	2.69	71.2
60	12.0	65.3	2.17	75.7
90	6.8	79.7	1.26	83.7
120	6.9	79.2		
0 vs. nutsedge	***	---	***	---
TD (30 to 120)	L***	L***	Q**	Q*

[z]Values were expressed as percent loss relative to those obtained with 0 TD.

[NS, *, **, ***]Effects were nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively, according to F tests. Competition (30 to 120 TD) vs. no competition (0 TD) effects were tested with contrasts. Tuber density effects were linear (L) or quadratic (Q) according to polynomial contrasts.

Table 1-27. Season, in-row pepper spacing, and initial nutsedge tuber density effects on pepper plant fruit dry weight during pepper fruit development 10 and 9 weeks after pepper transplanting in spring and fall, respectively, in 2000.

	Fruit wt per plant	
Treatment	dry wt (g)	loss (%)[Z]
Season		
Spring	15.82	58.5
Fall	1.33	61.5
Signif.	***	NS
Pepper spacing (cm)		
22.9	8.93	62.2
30.5	9.83	57.5
Signif.	NS	NS
Tuber density (TD; no.$\cdot$m^{-2})		
0	19.17	---
15	12.01	39.6
30	8.25	61.4
45	6.58	70.3
60	5.26	74.3
90	5.02	77.2
0 vs. nutsedge	***	---
TD (30 to 120)	Q***	Q*

[Z]Values were expressed as percent loss relative to those obtained with 0 TD.

[NS, *, **, ***]Effects were nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively, according to F tests. Competition (15 to 90 TD) vs. no competition (0 TD) effects were tested with contrasts. Tuber density effects were quadratic (Q) according to orthogonal contrasts.

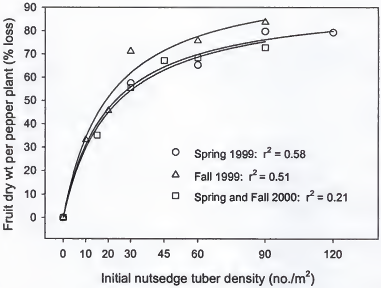


Fig. 1-6. Initial nutsedge tuber density effect on fruit dry weight loss per pepper plant, relative to that with pepper grown weed-free, during pepper fruit development in spring 1999, fall 1999, and 2000. Data for spring and fall in 2000 were pooled. Coefficients of determination (r^2 values) were obtained by regressing data within means (shown).

Table 1-28. Coefficients for the rectangular hyperbola [$Y = A \times X/(B + X)$] used to characterize the effect of initial yellow nutsedge tuber density on N uptake of bell pepper fruit sampled during pepper fruit development.

Parameter[Z]	
A	B
Spring 1999	
93.0 ± 6.8	20.0 ± 6.2
Fall 1999	
103.8 ± 11.1	20.3 ± 6.3
Spring and fall 2000	
93.2 ± 13.5	21.5 ± 9.6

[Z]Coefficients ± standard errors for each variable were obtained with data within means.

Table 1-29. Main effects of in-row bell pepper spacing and initial yellow nutsedge tuber density on total dry weight per pepper plant [sum of leaf, stem, and fruit (if present) dry weight] during pepper flowering, fruit development, and after final fruit harvest in spring 1999.

	Total dry wt at three growth stages (g and % loss)					
	Flowering[Z]		Fruit		Fruit harvest	
Treatment	g	% loss[Y]	g	% loss	g	% loss
Pepper spacing (cm)						
22.9	7.06	30.3	35.36	62.04	25.53	50.61
30.5	7.45	40.8	36.61	67.80	29.31	55.12
Signif.	NS	*	NS	NS	*	NS
Tuber density (TD; no.$\cdot m^{-2}$)						
0	10.25	---	75.47	---	48.62	---
30	8.09	20.5	31.94	56.9	24.09	47.7
60	6.71	33.4	30.66	59.5	25.59	45.5
90	6.42	35.9	20.09	72.6	20.21	57.5
120	4.82	52.6	21.76	70.8	18.59	60.8
0 vs. nutsedge	***	---	***	---	***	---
TD (30 to 120)	L***	L***	C*	L***	L**	L**

[Z]Pepper plants were sampled during pepper flowering, fruit development, and after final fruit harvest 6, 10, and 14 weeks after pepper planting.

[Y]Values were expressed as percent loss relative to those obtained with 0 TD.

[NS, *, **, ***]Effects were nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively, according to F tests. Competition (30 to 120 TD) vs. no competition (0 TD) effects were tested with contrasts. Tuber density effects were linear (L) or cubic (C) according to polynomial contrasts.

Table 1-30. Main effects of in-row bell pepper spacing and initial yellow nutsedge tuber density on total dry weight per pepper plant [sum of leaf, stem, and fruit (if present) dry weight] during pepper flowering, fruit development, and after fruit harvest in fall 1999.

	Total dry wt at three growth stages (g and % loss)					
	Flowering[Z]		Fruit development		Fruit harvest	
Treatment	g	% loss[Y]	g	% loss	g	% loss
Pepper spacing (cm)						
22.9	4.95	63.0	9.78	52.8	6.90	53.7
30.5	5.31	63.6	10.16	57.5	7.59	60.0
Signif.	NS	NS	NS	NS	NS	NS
Tuber density (TD; no.$\cdot$m^{-2})						
0	10.85	---	19.23	---	14.06	---
10	6.90	35.2	13.42	26.5	8.71	37.0
20	5.03	54.7	10.30	41.3	6.97	49.7
30	3.77	65.9	7.43	60.5	5.50	60.7
60	2.56	76.1	5.15	72.0	4.16	67.5
90	1.65	84.8	4.28	75.5	4.07	69.5
0 vs. nutsedge	***	---	***	---	***	---
TD (10 to 90)	Q**	Q**	Q***	Q**	Q**	Q*

[Y]Pepper plants were sampled during pepper flowering, fruit development, and after fruit harvest 6, 9, and 13 weeks after pepper planting.

[Y]Values were expressed as percent loss relative to those obtained with 0 TD.

[NS, *, **, ***]Main effects were nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively, according to F tests. Competition (TD from 10 to 90) vs. no competition (0) effects were tested with contrasts. Tuber density effects were quadratic (Q) according to polynomial contrasts.

Table 1-31. Main effects of season, in-row bell pepper spacing, and initial yellow nutsedge tuber density on total dry weight per pepper plant [sum of leaf, stem, and fruit (if present)] during pepper flowering, fruit development, and after final fruit harvest in spring and fall 2000.

	Total dry wt at three growth stages (g and % loss)					
	Flowering[Z]		Fruit development		Fruit harvest	
Treatment	g	% loss[Y]	g	% loss	g	% loss
Season						
Spring	5.83	29.9	32.30	58.1	16.20	53.6
Fall	1.98	47.8	4.69	72.9	4.27	70.1
Signif.	***	*	***	**	***	**
Pepper spacing (cm)						
22.9	4.11	40.5	18.87	64.6	10.30	59.2
30.5	4.13	35.2	21.19	64.7	11.49	62.6
Signif.	NS	NS	*	NS	NS	NS
Tuber density (TD; no.$\cdot$m^{-2})						
0	6.21	---	40.55	---	21.71	---
15	5.06	15.2	24.85	39.6	12.23	43.6
30	4.26	25.6	17.42	61.4	9.12	60.1
45	3.36	41.8	14.34	70.9	8.13	64.5
60	3.11	50.0	11.93	74.3	7.04	68.5
90	2.71	56.5	11.07	77.2	7.15	67.9
0 vs. nutsedge	***	---	***	---	***	---
TD (15 to 90)	Q***	L***	Q***	C*	Q***	Q***

[Z]Pepper plants were sampled during pepper flowering, fruit development, and after final fruit harvest 6, 10, and 14 or 6, 9, and 14 weeks after pepper transplanting in spring and fall, respectively

[Y]Values were expressed as percent loss relative to those obtained with 0 TD.

[NS, *, **, ***]Effects were nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively, according to F tests. Competition (15 to 90 TD) vs. no competition (0 TD) effects were tested with contrasts. Tuber density effects were linear (L), quadratic (Q), or cubic (C) according to polynomial contrasts.

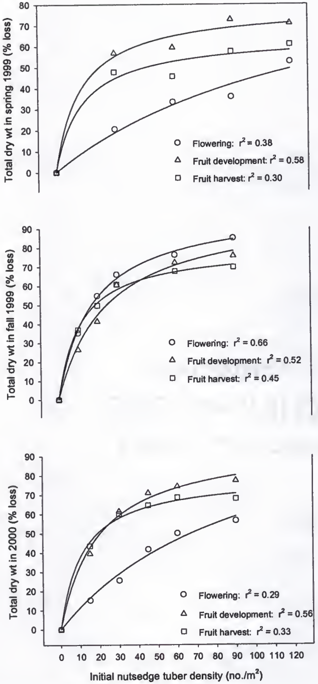


Fig. 1-7. Main effect of initial yellow nutsedge tuber density on total dry weight [leaf + stem + fruit (if present)] per pepper plant in spring 1999, fall 1999, and in 2000 as percent loss relative to that with no nutsedge. Data in spring and fall of 2000 were combined. Coefficients of determination (r^2 values) were determined by regressing data within means (shown).

Table 1-32. Coefficients for the rectangular hyperbola [$Y = A \times X/(B + X)$] used to characterize the effect of initial yellow nutsedge tuber density on loss of total bell pepper [leaf + stem + fruit (if present) tissue] dry weight.

	Parameter[z]	
Pepper growth stage	A	B
	Spring 1999	
Flowering	107.7 ± 52.3	142.5 ± 112.0
Fruit development	78.6 ± 4.8	12.8 ± 4.5
Fruit harvest	64.5 ± 7.1	13.5 ± 8.2
	Fall 1999	
Flowering	100.4 ± 7.0	17.2 ± 3.8
Fruit development	99.5 ± 12.1	24.6 ± 8.1
Fruit harvest	79.6 ± 6.5	11.2 ± 3.5
	Spring and fall 2000	
Flowering	120.1 ± 46.7	93.8 ± 59.5
Fruit development	96.8 ± 5.7	19.0 ± 3.7
Fruit harvest	79.3 ± 5.0	11.1 ± 3.1

[z]Coefficients ± standard errors for each variable were obtained with data within means. Models were significant at $P \leq 0.001$.

Table 1-33. Main effects of in-row bell pepper plant spacing (PS) and initial yellow nutsedge tuber density (TD) on pepper plant (leaf and stem tissue) and fruit N concentration in spring 1999.

	Plant N conc. at three stages (% dry wt)			Fruit N conc. (% dry wt)[Y]	
Treatment	Flowering[Z]	Fruit dev.	Fruit har.	Immature	Harvested
Pepper spacing (cm)					
22.9	3.94	2.54	1.78	2.22	2.61
30.5	4.16	2.60	1.83	2.19	2.63
Signif.	NS	NS	NS	NS	NS
Tuber density (TD; no.·m^{-2})					
0	4.70	2.52	2.12	2.20	2.56
30	4.22	2.47	1.85	2.16	2.62
60	3.94	2.62	1.71	2.32	2.67
90	3.67	2.52	1.78	2.19	2.68
120	3.72	2.73	1.56	2.13	2.58
0 vs. nutsedge	***	NS	***	NS	NS
TD (30 to 120)	L*	NS	L**	NS	NS

[Z]Pepper plants were sampled during pepper flowering, fruit development, and after final fruit harvest at 6, 10, and 14 weeks after pepper transplanting (WAT).

[Y]N concentrations were determined in sampled (during pepper fruit development) and harvested fruit. Harvested fruit N concentrations in two harvests were averaged.

[NS, *, **, ***]Effects were nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively, according to F tests. Competition (30 to 120 TD) vs. no competition effects were tested with contrasts. Significant tuber density effects were linear (L) according to polynomial contrasts.

Table 1-34. Main effects of in-row bell pepper plant spacing (PS) and initial yellow nutsedge tuber density (TD) on pepper plant (leaf and stem tissue) and fruit N concentration in fall 1999.

	Plant N conc. at three stages (% dry wt)			Fruit N conc. (% dry wt)[Y]	
Treatment	Flowering[Z]	Fruit dev.	Fruit har.	Immature	Harvested
Pepper spacing (cm)					
22.9	2.99	2.03	2.28	1.84	2.27
30.5	3.22	2.18	2.47	1.79	2.23
Signif.	*	*	**	NS	NS
Tuber density (TD; no.·m^{-2})					
0	2.93	2.06	2.13	1.77	2.04
10	2.80	2.16	2.17	1.97	2.26
20	2.93	2.14	2.25	2.07	2.24
30	3.08	2.03	2.35	1.73	2.33
60	3.42	2.02	2.61	1.73	2.25
90	3.46	2.23	2.74	1.62	2.37
0 vs. nutsedge	NS	NS	***	NS	**
TD (10 to 90)	L***	Q*	L***	L*	NS

[Z]Pepper plants were sampled during pepper flowering, fruit development, and after final fruit harvest at 6, 10, and 14 weeks after pepper transplanting (WAT).

[Y]N concentrations were determined in sampled (during pepper fruit development) and harvested fruit. Harvested fruit N concentrations in two harvests were averaged.

[NS, *, **, ***]Effects were nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively, according to F tests. Competition (10 to 90 TD) vs. no competition effects were tested with contrasts. Significant tuber density effects were linear (L) or quadratic (Q) according to polynomial contrasts.

Table 1-35. Main effects of in-row bell pepper plant spacing (PS) and initial yellow nutsedge tuber density (TD) on pepper plant (leaf and stem tissue) and fruit N concentration in spring and fall 2000.

	Plant N conc. at three stages (% dry			Fruit N conc. (% dry wt)[Y]	
Treatment	Flowering[Z]	Fruit dev.	Fruit har.	Immature	Harvested
Season					
Spring	2.73	2.11	1.41	1.11	2.77
Fall	2.66	2.74	1.68	1.15	1.33
Signif.	NS	***	**		
Pepper spacing (cm)					
22.9	2.66	2.36	1.52	1.15	2.24
30.5	2.74	2.42	1.55	1.11	2.02
Signif.	NS	NS	NS	NS	**
Tuber density (TD; no.$\cdot$m^{-2})					
0	3.14	2.61	1.61	1.68	2.33
15	2.85	2.34	1.52	1.49	2.30
30	2.69	2.35	1.50	1.27	2.16
45	2.46	2.28	1.53	0.79	2.10
60	2.53	2.39	1.52	0.93	1.92
90	2.55	2.39	1.51	0.60	1.97
0 vs. nutsedge	***	**	NS		
TD (15 to 90)	Q*	NS	NS		
Season X TD	NS	NS	NS	***	**

[Z]Pepper plants were sampled during pepper flowering, fruit development, and after final fruit harvest at 6, 10, and 14 weeks after pepper transplanting (WAT).

[Y]N concentrations were determined in sampled (during pepper fruit development) and harvested fruit. Harvested fruit N concentrations in two harvests were averaged.

[NS, *, **, ***]Effects were nonsignificant or significant at P ≤ 0.05, 0.01, or 0.001, respectively, according to F tests. Competition (15 to 90 TD) vs. no competition (0 TD) effects were tested with contrasts. The significant tuber density effect was quadratic (Q) according to a polynomial contrast.

Table 1-36. Interaction of season and initial yellow nutsedge tuber density in 2000 on N concentration in sampled (during fruit development; immature) and harvested bell pepper fruit.

	Tuber density (no.$\cdot$m^{-2})							
Season	0	15	30	45	60	90	0 vs nutsedge	Signif.[Z]
	N conc. in immature fruit (% dry wt)							
Spring	1.32	1.11	1.05	1.00	1.09	1.09	***	C*
Fall	2.12	1.95	1.55	0.52	0.73	0	**	L***
	N conc. in harvested fruit (% dry wt)							
Spring	2.75	2.66	2.84	2.80	2.73	2.84	NS	NS
Fall	1.80	1.85	1.30	1.23	0.90	0.88	*	L***

[Z]Values obtained with pepper grown weed-free (0) were excluded in tests for significance of pepper height response to tuber density.

[NS, *, **, ***]Row effects were nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001 according to F-tests. Competition (15 to 90 tubers$\cdot$m^{-2}) vs no competition (0 tubers$\cdot$m^{-2}) effects were tested with contrasts. Significant tuber density (15 to 90 tubers$\cdot$m^{-2}) were linear (L) or cubic (C) according to polynomial contrasts.

Table 1-37. Main effects of in-row bell pepper plant spacing and initial yellow nutsedge tuber density on pepper plant (leaf plus stem) N uptake during pepper flowering, fruit development, and after final fruit harvest in spring 1999.

	Plant N uptake at three growth stages ($kg \cdot ha^{-1}$ and % loss)					
	Flowering[Z]		Fruit development		Fruit harvest	
Treatment	$kg \cdot ha^{-1}$	% loss[Y]	$kg \cdot ha^{-1}$	% loss	$kg \cdot ha^{-1}$	% loss
Pepper spacing (cm)						
22.9	20.4	39.7	37.2	58.3	30.5	57.1
30.5	17.1	52.1	30.2	62.2	27.8	65.0
Signif.	**	**	**	NS	NS	NS
Tuber density (TD; $no. \cdot m^{-2}$)						
0	29.8	---	65.6	---	58.7	---
30	21.5	26.9	27.9	57.2	26.1	52.4
60	16.5	44.6	30.0	54.3	25.4	55.1
90	14.9	49.6	20.4	67.5	19.4	65.4
120	11.1	62.5	24.7	61.9	16.1	71.4
0 vs. nutsedge	***	---	***	---	***	---
TD (30 to 120)	L***	L***	C*	NS	L**	L**

[Z]Pepper plants were sampled during pepper flowering, fruit development, and after final fruit harvest 6, 10, and 14 weeks after pepper transplanting.

[Y]Values were expressed as percent loss relative to those obtained with 0 TD.

[NS, *, **, ***]Main effects were nonsignificant or significant at $P \leq 0.05, 0.01$, or 0.001, respectively, according to F tests. Competition (30 to 120 TD) vs. no competition (0 TD) effects were tested with contrasts. Significant tuber density effects were linear (L) or cubic (C) according to polynomial contrasts.

Table 1-38. Main effects of in-row bell pepper plant spacing and initial yellow nutsedge tuber density on N uptake by pepper plants (leaf plus stem tissue) sampled during pepper flowering, fruit development, and after fruit harvest in fall 1999.

	Plant N uptake at three growth stages ($kg \cdot ha^{-1}$ and % loss)					
	Flowering[Z]		Fruit development		Fruit harvest	
Treatment	$kg \cdot ha^{-1}$	% loss[Y]	$kg \cdot ha^{-1}$	% loss	$kg \cdot ha^{-1}$	% loss
Pepper spacing (cm)						
22.9	10.9	58.2	8.16	43.0	10.88	45.5
30.5	9.2	64.8	7.04	57.6	9.81	52.4
Signif.	NS	NS	NS	*	NS	NS
Tuber density (TD; $no. \cdot m^{-2}$)						
0	20.1	---	13.38	---	18.09	---
10	12.9	38.1	10.56	19.0	11.59	33.8
20	10.1	53.3	7.28	39.6	9.96	43.8
30	7.8	63.8	6.26	54.1	8.14	53.7
60	5.6	70.3	3.77	70.9	7.12	56.0
90	3.6	82.0	4.36	67.9	7.17	57.7
0 vs. nutsedge	***	---	***	---	***	---
TD (10 to 90)	L***	L***	Q**	Q**	Q*	L*

[Z]Pepper plants were sampled during pepper flowering, fruit development, and after final fruit harvest 6, 9, and 14 weeks after pepper transplanting.

[Y]Values were expressed as percent loss relative to those obtained with 0 TD.

[NS, *, **, ***]Effects were nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively, according to F tests. Competition (10 to 90 TD) vs. no competition (0 TD) effects were tested with contrasts. Significant tuber density effects were linear (L) or quadratic (Q) according to polynomial contrasts.

Table 1-39. Main effects of season, in-row bell pepper plant spacing and initial yellow nutsedge tuber density on N uptake by pepper plants (leaf plus stem tissue) sampled during pepper flowering, fruit development, and after fruit harvest in 2000.

	Plant N uptake at three growth stages ($kg{\cdot}ha^{-1}$ and % loss)					
	Flowering[Z]		Fruit development		Fruit harvest	
Treatment	$kg{\cdot}ha^{-1}$	% loss[Y]	$kg{\cdot}ha^{-1}$	% loss	$kg{\cdot}ha^{-1}$	% loss
Season (S)						
Spring	10.18	42.8	21.17	61.4	12.53	61.5
Fall	3.82	51.7	5.86	73.9	4.29	70.2
Signif.	***	NS	***	*	***	
Pepper spacing (cm)						
22.9	8.13	50.6	15.06	63.3	9.47	63.1
30.5	6.57	42.9	13.67	70.5	8.26	67.6
Signif.	**	NS	NS	**	*	
S X Pepper spacing	NS	NS	NS	NS	NS	*
Tuber density (TD; no.$\cdot m^{-2}$)						
0	12.84	---	31.37	---	19.57	---
15	9.20	23.5	16.91	46.3	9.66	48.3
30	7.60	32.9	11.59	65.7	7.13	64.5
45	5.27	54.2	9.71	72.0	6.11	69.4
60	4.97	59.9	8.77	73.9	5.29	72.3
90	4.23	63.2	7.84	76.6	5.42	72.4
0 vs. nutsedge	***	---	***	---	***	---
TD (15 to 90)	Q***	Q*	Q***	C*	Q***	Q***

[Z]Pepper plants sampled during flowering, fruit deveolopment, and after final fruit harvest 6, 10, and 14 or 6, 9, and 14 weeks after pepper transplanting in spring and fall, respectively

[Y]Values were expressed as percent loss relative to those obtained with 0 TD.

[NS, *, **, ***]Effects were nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively, according to F tests. Competition (15 to 90 TD) vs. no competition (0 TD) effects were tested with contrasts. Tuber density effects were quadratic (Q) according to polynomial contrasts.

Table 1-40. Interaction of season and in-row bell pepper plant spacing on N uptake by pepper plants (leaf plus stem tissue) after final fruit harvest in 2000.

	In-row pepper spacing (cm)		
	23	31	
Season	Plant N upake ($kg \cdot ha^{-1}$)		Signif.
Spring	57	66	***
Fall	71	69	NS
Signif.	NS	NS	

NS, ***Column and row effects were nonsignificant or significant at $P \leq 0.001$ according to F-tests.

Table 1-41. Main effects of in-row bell pepper plant spacing and initial yellow nutsedge tuber density on N uptake by developing and harvested pepper fruit in spring 1999.

	Fruit N uptake (kg·ha^{-1} and % loss)			
	Immature[Z]		Harvested	
Treatment	kg·ha^{-1}	% loss[Y]	kg·ha^{-1}	% loss
Pepper spacing (cm)				
22.9	23.3	66.8	28.6	67.6
30.5	17.6	73.1	25.7	73.8
Signif.	**	NS	**	**
Tuber density (TD; no.·m^{-2})				
0	46.7	---	62.5	---
30	19.1	58.4	24.8	60.4
60	16.5	63.7	20.0	68.0
90	9.8	79.3	17.2	72.5
120	10.2	78.4	11.2	81.8
0 vs. nutsedge	***	---	***	---
TD (30 to 120)	L***	L***	L***	L***

[Z]Pepper plants were sampled during pepper fruit development at 10 weeks after pepper transplanting. Harvested fruit N uptake was the sum of that for each fruit harvest.

[Y]Values were expressed as percent loss relative to those obtained with 0 TD.

[NS, *, **, ***]Main effects were nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively, according to F tests. Competition (30 to 120 TD) vs no competition (0 TD) effects were tested with contrasts. Tuber density effects were linear (L) according to polynomial contrasts.

Table 1-42. Main effects of in-row bell pepper plant spacing and initial yellow nutsedge tuber density on N uptake by developing and harvested pepper fruit in fall 1999.

	Fruit N uptake ($kg{\cdot}ha^{-1}$ and % loss)			
	Immature[Z]		Harvested	
Treatment	$kg{\cdot}ha^{-1}$	% loss[Y]	$kg{\cdot}ha^{-1}$	% loss
Pepper spacing (cm)				
22.9	5.70	56.6	6.43	60.0
30.5	4.88	68.4	6.50	64.3
Signif.	NS	*	NS	NS
Tuber density (TD; no.$\cdot m^{-2}$)				
0	11.44	---	13.59	---
10	6.94	35.3	9.66	28.0
20	5.57	46.5	7.22	45.9
30	3.47	70.9	5.24	62.6
60	2.59	77.2	2.05	82.8
90	1.73	82.7	1.04	91.5
0 vs. nutsedge	***	---	***	---
TD (10 to 90)	Q**	Q**	Q**	Q**

[Z]Pepper plants were sampled during pepper fruit development at 9 weeks after pepper transplanting. Harvested fruit N uptake was the sum of that for each fruit harvest.

[Y]Values were expressed as percent loss relative to those obtained with 0 TD.

[NS, *, **, ***]Effects were nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively, according to F tests. Competition (10 to 90 TD) vs. no competition (0 TD) effects were tested with contrasts. Effects were quadratic (Q) according to polynomial contrasts.

Table 1-43. Main effects of season, in-row bell pepper plant spacing and initial yellow nutsedge tuber density effects on N uptake by developing and harvested pepper fruit in 2000.

	Fruit N uptake ($kg \cdot ha^{-1}$ and % loss)			
	Immature[Z]		Harvested	
Treatment	$kg \cdot ha^{-1}$	% loss[Y]	$kg \cdot ha^{-1}$	% loss
Season (S)				
Spring	20.24	60.1	28.13	65.2
Fall	2.06	60.3	3.81	84.3
Signif.	***	NS	***	***
Pepper spacing (cm)				
22.9	13.13	60.5	18.12	71.2
30.5	11.18	60.0	16.52	76.1
Signif.	*	NS	*	*
Tuber density (TD; $no. \cdot m^{-2}$)				
0	25.65	---	40.09	---
15	15.83	33.4	21.17	50.6
30	10.36	56.2	14.35	70.4
45	7.93	69.3	11.12	78.5
60	6.90	69.0	9.59	82.3
90	6.28	73.2	7.6	86.5
0 vs. nutsedge	***	---	***	---
TD (15 to 90)	Q***	Q**	Q**	Q***

[Z]Pepper plants were sampled during fruit development at 10 or 9 weeks after pepper transplanting in spring and fall, respectively. Harvested fruit N uptake was the sum of that for each fruit harvest.

[Y]Values were expressed as percent loss relative to those obtained with 0 TD.

[NS, *, **, ***]Effects were nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively, according to F tests. Competition (15 to 90 TD) vs. no competition (0 TD) effects were tested with contrasts. Tuber density effects were quadratic (Q) according to polynomial contrasts.

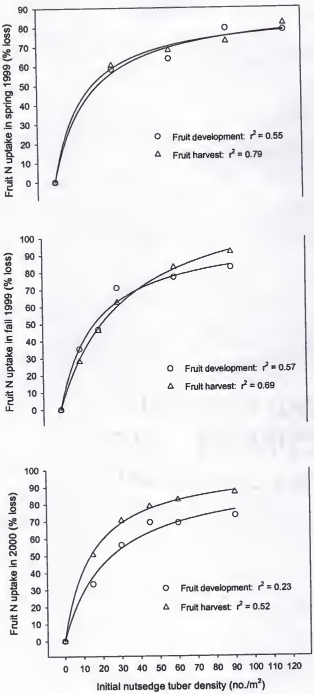


Fig. 1-8. Main effect of initial yellow nutsedge tuber density on N uptake of developing (immature) and harvested fruit in spring 1999, fall 1999, and in 2000 as percent loss relative to that with no nutsedge. Data in spring and fall of 2000 were combined. Coefficients of determination (r^2 values) were determined by regressing data within means (shown).

Table 1-44. Coefficients for the rectangular hyperbola [$Y = A \times X/(B + X)$] used to characterize the effect of initial yellow nutsedge tuber density on loss of bell pepper fruit N uptake.

	Parameter^{Z}	
Pepper growth stage	A	B
	Spring 1999	
Fruit development	90.7 ± 6.9	18.3 ± 6.3
Fruit harvest	87.8 ± 3.4	14.9 ± 2.9
	Fall 1999	
Fruit development	101.8 ± 9.1	18.7 ± 5.0
Fruit harvest	127.5 ± 13.5	33.6 ± 8.4
	Spring and fall 2000	
Fruit development	96.1 ± 13.8	23.0 ± 9.8
Fruit harvest	101.8 ± 5.2	14.3 ± 2.8

^{Z}Coefficients ± standard errors for each variable were obtained with data within means. Models were significant at $P \leq 0.001$.

Table 1-45. Main effects of in-row bell pepper plant spacing and initial yellow nutsedge tuber density effects on total pepper N uptake during pepper fruit development and at final pepper fruit harvest in spring 1999.

	Total N uptake at two stages ($kg \cdot ha^{-1}$ and % loss)			
	Fruit development[Z]		Fruit harvest	
Treatment	$kg \cdot ha^{-1}$	% loss[Y]	$kg \cdot ha^{-1}$	% loss
Pepper spacing (cm)				
22.9	60.5	61.9	59.1	62.8
30.5	47.8	66.8	53.4	70.0
Signif.	**	NS	NS	*
Tuber density (TD; $no. \cdot m^{-2}$)				
0	112.2	---	121.2	---
30	47.0	57.9	50.9	57.1
60	46.5	58.2	45.4	62.1
90	30.2	72.4	36.6	69.3
120	34.8	68.8	27.3	77.2
0 vs. nutsedge	***	---	***	---
TD (30 to 120)	C*	L**	L***	L***

[Z]Pepper plants were sampled during pepper flowering, fruit development, and at fruit harvest at 6, 10, and 14 weeks after pepper planting. Leaf, stem, and fruit (if present; for the third sampling, fruit N uptake for each harvest was summed) N uptake was summed.

[Y]Values were expressed as percent loss relative to those obtained with 0 TD.

[NS, *, **, ***]Effects were nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively, according to F tests. Competition (30 to 120 TD) vs no competition (0 TD) effects were tested with contrasts. Tuber density effects were linear (L) or cubic (C) according to polynomial contrasts.

Table 1-46. Main effects of in-row bell pepper plant spacing and initial yellow nutsedge tuber density effects on total pepper N uptake during pepper fruit development and at fruit harvest in fall 1999.

	Total N uptake at two stages ($kg{\cdot}ha^{-1}$ and % loss)			
	Fruit development[Z]		Fruit harvest	
Treatment	$kg{\cdot}ha^{-1}$	% loss[Y]	$kg{\cdot}ha^{-1}$	% loss
Pepper spacing (cm)				
22.9	13.9	50.8	17.3	52.2
30.5	12.1	64.0	16.3	58.4
Signif.	NS	**	NS	NS
Tuber density (TD; $no.{\cdot}m^{-2}$)				
0	25.5	---	31.7	---
10	17.5	29.7	21.2	32.3
20	12.8	44.3	17.2	45.2
30	9.7	63.1	13.4	58.1
60	6.4	74.5	9.2	68.0
90	6.1	75.6	8.2	72.8
0 vs. nutsedge	***	---	***	---
TD (10 to 90)	Q***	Q***	Q**	Q*

[Z]Pepper plants were sampled during pepper flowering, fruit development, and at fruit harvest 6, 10, and 14 weeks after pepper planting. Leaf, stem, and fruit (if present; for the third sampling, fruit N uptake for each harvest was summed) N uptake was summed.

[Y]Values were expressed as percent loss relative to those obtained with 0 TD.

[NS, *, **, ***]Effects were nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively, according to F tests. Competition (10 to 90 TD) vs. no competition (0 TD) effects were tested with contrasts. Tuber density effects were quadratic (Q) according to polynomial contrasts.

Table 1-47. Main effects of season, in-row bell pepper plant spacing and initial yellow nutsedge tuber density on total pepper N uptake during pepper fruit development and at fruit harvest in spring and fall 2000.

	Total N uptake at two stages (kg·ha^{-1} and % loss)			
	Fruit development[Z]		Fruit harvest	
Treatment	kg·ha^{-1}	% loss[Y]	kg·ha^{-1}	% loss
Season				
Spring	41.40	61.5	40.66	64.3
Fall	7.92	75.4	8.10	79.2
Signif.	***	***	***	***
Pepper spacing (cm)				
22.9	28.19	66.0	27.59	69.0
30.5	24.85	69.4	24.78	72.8
Signif.	**	NS	*	**
Tuber density (TD; no.·m^{-2})				
0	57.02	---	59.66	---
15	32.74	43.9	30.83	50.6
30	21.95	65.2	21.48	68.8
45	17.64	74.3	17.23	75.1
60	15.67	76.1	14.88	78.7
90	14.12	79.0	13.03	81.3
0 vs. nutsedge	***	---	***	---
TD (15 to 90)	Q***	C**	Q**	C**

[Z]Pepper plants were sampled during pepper flowering, fruit development, and at fruit harvest 6, 10, and 14 weeks after pepper planting. Leaf, stem, and fruit (if present; for the third sampling, fruit N uptake for each harvest was summed) N uptake was summed.

[Y]Values were expressed as percent loss relative to those obtained with 0 TD.

[NS, *, **, ***]Effects were nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively, according to F tests. Competition (15 to 90 TD) vs. no competition (0 TD) effects were tested with contrasts. Tuber density effects were quadratic (Q) or cubic (C) according to polynomial contrasts.

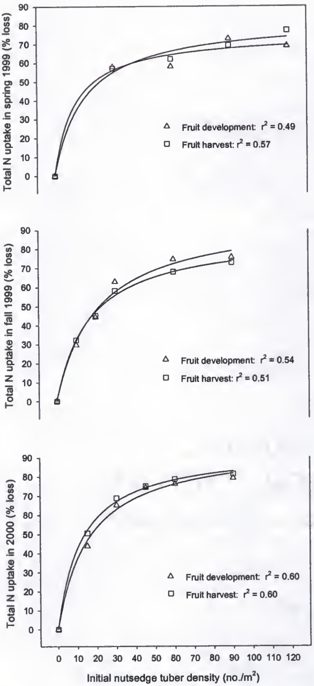


Fig. 1-9. Main effect of initial yellow nutsedge tuber density on total bell pepper N uptake [sum of plant and fruit N uptake] in spring 1999, fall 1999, and in 2000 as percent loss relative to that with no nutsedge, Data in spring and fall of 2000 were combined. Coefficients of determination (r^2 values) were determined by regressing data within means (shown).

Table 1-48. Coefficients for the rectangular hyperbola [$Y = A \times X/(B + X)$] used to characterize the effect of initial yellow nutsedge tuber density on total bell pepper N uptake as percent loss relative to that with no nutsedge.

Pepper growth stage	Parameter[z] A	Parameter[z] B
	Spring 1999	
Flowering	104.3 ± 28.5	86.4 ± 46.2
Fruit development	75.4 ± 5.1	10.4 ± 4.6
Fruit harvest	83.3 ± 5.5	15.6 ± 5.1
	Fall 1999	
Flowering	91.9 ± 7.9	14.3 ± 4.2
Fruit development	97.0 ± 10.0	20.7 ± 6.2
Fruit harvest	87.3 ± 8.2	17.0 ± 5.0
	Spring and fall 2000	
Flowering	107.1 ± 27.1	56.0 ± 27.9
Fruit development	96.0 ± 4.5	15.7 ± 2.7
Fruit harvest	94.0 ± 3.6	12.0 ± 1.9

[z]Coefficients ± standard errors for each variable were obtained with data within means. Models were significant at $P \leq 0.001$.

Table 1-49. Main effects of in-row bell pepper plant spacing and initial yellow nutsedge tuber density on nutsedge shoot height and number during pepper flowering, fruit development, and at final fruit harvest in spring 1999.

	Nutsedge shoot ht (cm) and number (no.·$0.1m^{-2}$) at pepper growth stages[Z]					
	Flowering		Fruit development		Fruit harvest	
Treatment	ht	no.	ht	no.	ht	no.
Pepper spacing (cm)						
22.9	49	---[Y]	68	164	73	251
30.5	49	---	67	179	72	280
Signif.	NS	---	NS	NS	NS	*
Tuber density (TD;						
30	45	---	67	139	73	223
60	48	---	69	177	74	282
90	50	---	67	188	71	271
120	53	---	67	184	71	287
Signif.	L***	---	NS	L**	NS	L**

[Z]Nutsedge shoot heights were measured and shoot counts obtained during pepper flowering, fruit development, and at final fruit harvest 6, 10, and 13 weeks after pepper transplanting (WAT).

[Y]Data were not obtained.

[NS, *, **, ***]Effects were nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively, according to F tests. Significant tuber density effects were linear (L) according to polynomial contrasts.

Table 1-50. Main effects of in-row bell pepper plant spacing and initial yellow nutsedge tuber density on nutsedge shoot height and number during pepper flowering, fruit development, and at fruit harvest in fall 1999.

	Nutsedge shoot ht (cm) and number (no.$\cdot$0.1m^{-2}) at pepper growth stages[Z]					
	Flowering		Fruit development		Fruit harvest	
Treatment	ht	no.	ht	no.	ht	no.
Pepper spacing (cm)						
22.9	59	57	52	42	43	37
30.5	59	63	52	49	43	34
Signif.	NS	NS	NS	*	NS	NS
Tuber density (TD;						
10	57	58	51	40	41	28
20	58	59	53	42	43	29
30	61	52	52	40	44	37
60	59	62	53	50	44	46
90	60	68	51	55	42	46
Signif.	NS	L**	NS	L**	Q*	L***

[Z] Nutsedge shoot heights and counts were obtained during pepper flowering, fruit development, and at fruit harvest 6, 9, and 12 weeks after pepper transplanting.

[NS, *, **, ***] Effects were nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively, according to F tests. Significant tuber density effects were linear (L) or quadratic (Q) according to polynomial contrasts.

Table 1-51. Main effects of season, in-row bell pepper plant spacing and initial yellow nutsedge tuber density on nutsedge shoot height and number during pepper flowering, fruit development, and at fruit harvest in spring and fall 2000.

	Nutsedge shoot ht (cm) and number (no.·$0.1m^{-2}$) at pepper growth stages[Z]					
	Flowering		Fruit development		Fruit harvest	
Treatment	ht	no.	ht	no.	ht	no.
Season						
Spring	39.7	73	79.3	130	53.6	125
Fall	70.7	89	66.7	58	44.9	34
Signif.			***	***	***	***
Pepper spacing (cm)						
22.9	54.3	78	74.1	96	50.8	86
30.5	52.6	83	73.4	101	48.7	82
Signif.	**	NS	NS	NS	NS	NS
Tuber density (TD; no.·m^{-2})						
15	47.3	63	73.9	90	51.9	75
30	51.2	69	73.7	85	49.4	83
45	53.7	76	75.4	100	48.9	81
60	56.8	83	73.9	98	49.2	83
90	58.5	111	71.9	117	49.4	101
Signif.			Q*	L***	NS	L***
Season X TD	**	*	NS	NS	NS	NS

[Z] Nutsedge shoot heights and counts were obtained during pepper flowering, fruit development, and at fruit harvest 6, 10, and 14 weeks after pepper transplanting.

[NS, *, **, ***] Effects were nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively, according to F tests. Significant tuber density effects were linear (L) or quadratic (Q) according to polynomial contrasts.

Table 1-52. Interaction of season and initial yellow nutsedge tuber density on nutsedge shoot height and number during pepper flowering and on nutsedge shoot N concentration at pepper fruit harvest time in 2000.

	Tuber density (no.·m^{-2})					
Season	15	30	45	60	90	Signif.
	Ht at pepper flowering (cm)					
Spring	36	36	39	43	44	C*
Fall	62	70	72	74	76	Q***
	Number at pepper flowering (no.·0.1 m^{-2})					
Spring	43	66	69	77	110	C*
Fall	87	73	86	90	112	L*
	N conc. at pepper fruit harvest (% dry wt)					
Spring	0.76	0.73	0.71	0.76	0.73	NS
Fall	0.61	0.61	0.70	0.71	0.76	L***

$^{NS, *, ***}$Row effects were nonsignificant or significant at $P \leq 0.05$ or 0.001 according to F-tests. Significant tuber density effects were linear (L), quadratic (Q), or cubic (C) according to polynomial contrasts.

Table 1-53. Main effects of in-row bell pepper plant spacing and initial yellow nutsedge tuber density on nutsedge shoot N concentration and uptake during pepper flowering, fruit development, and at final fruit harvest in spring 1999.

	Nutsedge shoot N conc. (% dry wt.) and uptake ($kg \cdot ha^{-1}$) at pepper growth stages[Z]					
	Flowering		Fruit development		Fruit harvest	
Treatment	Conc.	Uptake	Conc.	Uptake	Conc.	Uptake
Pepper spacing (cm)						
22.9	2.49	---[Y]	1.27	171	1.19	174
30.5	2.59	---	1.27	194	1.14	184
Signif.	NS	---	NS	NS	NS	NS
Tuber density (TD; $no. \cdot m^{-2}$)						
30	2.65	---	1.26	156	1.25	157
60	2.67	---	1.31	192	1.17	199
90	2.45	---	1.26	183	1.19	187
120	2.37	---	1.25	199	1.04	171
Signif.	L*	---	NS	NS	L**	Q**

[Z]Nutsedge shoots were sampled for total kjeldahl N analysis during pepper flowering, fruit development, and at fruit harvest 6, 10, and 13 weeks after pepper transplanting.

[Y]Values could not be calculated due to lack of shoot count data.

[NS, **, ***]Effects were nonsignificant or significant at $P \leq 0.01$ or 0.001, respectively, according to F tests with analysis of variance. Significant tuber density effects were linear (L) or quadratic (Q) according to polynomial contrasts.

Table 1-54. Main effects of in-row bell pepper plant spacing and initial yellow nutsedge tuber density on nutsedge shoot N concentration and uptake during pepper flowering, fruit development, and at fruit harvest in fall 1999.

	Nutsedge shoot N conc. (% dry wt.) and uptake ($kg \cdot ha^{-1}$) at pepper growth stages[Z]					
	Flowering		Fruit development		Fruit harvest	
Treatment	Conc.	Uptake	Conc.	Uptake	Conc.	Uptake
Pepper spacing (cm)						
22.9	1.84	85	0.94	31	0.87	31
30.5	1.92	80	0.98	33	0.90	29
Signif.	NS	NS	NS	NS	NS	NS
Tuber density (TD;						
10	1.97	92	1.05	34	0.93	28
20	1.98	87	1.00	29	0.86	22
30	1.88	69	0.92	28	0.86	34
60	1.78	86	0.94	35	0.86	36
90	1.77	76	0.88	34	0.90	29
Signif.	L***	NS	L***	NS	Q*	NS

[Z]Nutsedge shoots were sampled for total kjeldahl N analysis during pepper flowering, fruit development, and at fruit harvest 6, 9, and 12 weeks after pepper transplanting.

[NS, *, ***]Effects were nonsignificant or significant at $P \leq 0.05$ or 0.001, respectively, according to F tests. Significant tuber density effects were linear (L) or quadratic (Q) according to polynomial contrasts.

Table 1-55. Main effects of in-row bell pepper plant spacing and initial yellow nutsedge tuber density on nutsedge shoot N concentration and uptake during pepper flowering, fruit development, and at final fruit harvest in 2000.

	Nutsedge shoot N conc. (% dry wt.) and uptake ($kg \cdot ha^{-1}$) at pepper growth stages[Z]					
	Flowering		Fruit development		Fruit harvest	
Treatment	Conc.	Uptake	Conc.	Uptake	Conc.	Uptake
Season						
Spring	2.26	46	1.29	114	0.74	58
Fall	1.42	66	1.38	74	0.68	27
Signif.	***	***	NS	**		***
Pepper spacing (cm)						
22.9	1.89	53	1.35	96	0.71	45
30.5	1.88	57	1.31	96	0.71	43
Signif.	NS	NS	NS	NS	NS	NS
Tuber density (TD;						
15	1.99	39	1.37	82	0.69	35
30	1.98	46	1.31	81	0.68	37
45	1.93	54	1.34	93	0.71	46
60	1.81	61	1.31	100	0.74	47
90	1.72	75	1.31	124	0.74	53
Signif.	L***	L***	NS	L***		L***
Season X TD	NS	NS	NS	NS	**	NS

[Z]Nutsedge shoots were sampled for total kjeldahl N analysis during pepper flowering, fruit development, and at final fruit harvest 6, 10, and 14 or 6, 9, and 14 weeks after pepper transplanting in spring and fall, respectively.

[NS, **, ***]Effects were nonsignificant or significant at $P \leq 0.01$ or 0.001, respectively, according to F tests. Significant tuber density effects were linear (L) according to polynomial contrasts.

Table 1-56. Main effects of season, in-row bell pepper plant spacing, and initial yellow nutsedge tuber density on interception of light by nutsedge shoots during pepper flowering and fruit development in 2000.

	Light intercepted by nutsedge at pepper growth stages[Z]	
	Flowering	Fruit development
Treatment	% available light	(%)
Season (S)		
Spring	26.6	47.2
Fall	72.2	73.0
Signif.		
Pepper spacing (PS; cm)		
22.9	47.3	59.7
30.5	46.5	57.6
Signif.		
Tuber density (TD; no.·m⁻		
15	25.8	36.6
30	41.2	53.8
45	51.1	67.4
60	53.7	67.5
90	62.5	68.0
S X TD	***	
PS X TD	*	
S X PS X TD	NS	*

[Z]Light [photosynthetic flux density (μ mol·m^{-2}·sec^{-1})] readings were obtained during pepper flowering and fruit development at 6 and 10 weeks after pepper transplanting (WAT) in spring and 6 and 9 WAT in fall, respectively. Readings were taken above each plot (available) and flush with the top of pepper plants. Data were converted to percent of available light intercepted by nutsedge.

[NS, *, ***]Effects were nonsignificant or significant at $P \leq 0.05$ or 0.001, respectively, according to F tests.

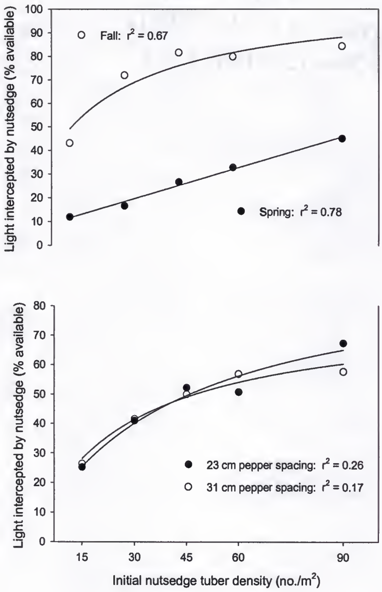


Fig. 1-10 Interaction of season and initial yellow nutsedge tuber density and in-row pepper spacing and season on interception of light by nutsedge during pepper flowering in 2000. Coefficients of determination (r^2) were obtained by regressing data within means (shown).

Table 1-57. Equations used to characterize the effect of initial yellow nutsedge tuber density on interception of light by nutsedge shoots in spring and fall of 2000.

Independent variable	Equation[z]
Season by tuber density interaction	
Spring 2000	$Y = 4.77 + 0.45(X)$
Fall 2000	$Y = 104.7 \times X/(17.0 + X)$
In-row pepper spacing by tuber density interaction	
23 cm pepper spacing	$Y = 94.4 \times X/(40.8 + X)$
31 cm pepper spacing	$Y = 78.2 \times X/(26.7 + X)$
Season by in-row pepper spacing by tuber density interaction	
23 cm pepper spacing in spring	$Y = 79.9 \times X/(25.7 + X)$
31 cm pepper spacing in spring	$Y = 13.3 + 1.38(X) - 0.011(X^2)$
23 cm pepper spacing in fall	$Y = 100.9 \times X/(13.5 + X)$
31 cm pepper spacing in fall	$Y = -239.0 + 322.8 \times (1 - e^{(-0.124 \times X)})$

[z]Models were significant at $P \leq 0.001$.

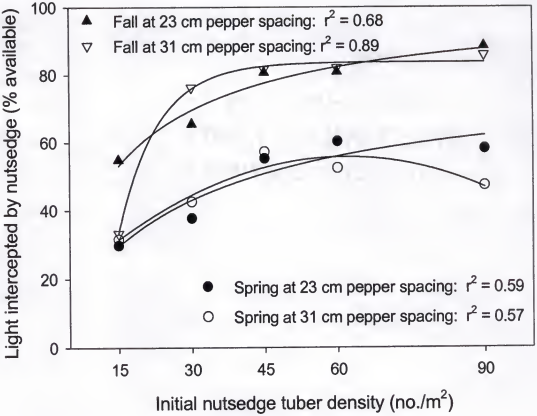


Fig. 1-11. Interaction of season, in-row pepper spacing, and initial yellow nutsedge tuber density on interception of light by nutsedge during pepper flowering in 2000. Coefficients of determination (r^2) were determined by regressing data within means (shown).

CHAPTER 2
CRITICAL YELLOW NUTSEDGE-FREE PERIOD FOR BELL PEPPER FRUIT PRODUCTION AND VEGETATIVE GROWTH

Introduction

Weed control is needed to produce adequate crop yields because a crop usually cannot tolerate season-long weed interference without substantial yield loss. It may not be necessary, however, to control weeds during the entire growing season. For instance, weeds emerging simultaneously with crop plants may be allowed to compete with the crop for a short time without substantially reducing crop yields. In addition, weed control practices may not need to continue for the duration of the season. The time period during which it is necessary to control weeds is known as the critical period.

The critical nutsedge-free period has been determined for several vegetable crops. One of the most important factors determining the critical weed-free period for a crop is the ability of the crop to produce a leaf canopy. William and Warren (1975) determined that the critical purple-nutsedge-free period for a tomato crop was between 3 and 5 weeks after crop establishment. For garlic, it was necessary to control purple nutsedge between the 3rd and 13th week after crop establishment. The longer weed-free period needed for garlic than tomato was attributed to the ability of tomato plants to produce a leaf canopy that shaded nutsedge plants.

The critical period for 10% loss of marketable tomato fruit yield due to yellow nutsedge interference was between 3 and 6 WAT (Morales-Payan, 1999). There are no

reports, however, of the critical period for yellow nutsedge interference with bell pepper. With the ongoing phaseout of methyl bromide, yellow nutsedge control is expected to be a concern. Therefore, this research was conducted to determine how long yellow nutsedge may be allowed to compete with bell pepper and when control practices may be stopped while still maintaining acceptable fruit production.

Materials and Methods

Treatment Design

Experiments were conducted in spring and fall of 2000 at the Horticultural Research Unit of the University of Florida in Gainesville, Fla. During spring 2000, a study was conducted on a Kanapaha fine sand (loamy siliceous, hyperthermic, Grossarenic Paleaquult) and a second study on an Arredondo fine sand (loamy, siliceous, hyperthermic, Grossarenic Paleudult). In Fall 2000, two studies were conducted on an Arredondo fine sand (loamy, siliceous, hyperthermic, Grossarenic Paleudult). In each season, the study designated as "A" was located westward of the study designated as "B".

Within each study, two single factor experiments, plant back and removal, were conducted adjacent to each other in each season. Treatments for the plant back experiment were nutsedge planting times of 0 (season-long interference), 1, 3, 5, 7, and 13 (season-long weed-free) weeks after pepper transplanting (WAT). For the removal experiment, treatments were nutsedge removal times of 0 (season-long weed-free), 1, 3, 5, 7, and 13 (season-long interference) WAT. Treatments were arranged in a randomized complete block design and replicated five times in each experiment.

Establishment and Maintenance Procedures

Beds were formed on 1.2 m centers, fumigated with 392 kg·ha^{-1} of 75:25 methyl bromide:chloropicrin injected 20 cm deep with two shanks to kill existing tubers, and covered with polyethylene mulch (Sonoco; 0.0038 cm thickness; black in spring; white in fall). Holes for pepper transplants were punched within one to two weeks after fumigation with a planting wheel to form double rows of holes spaced 30.5 cm apart in the rows. On the day pepper planting holes were punched, holes for nutsedge seedlings were punched in all plots via a board with dowels 7.6 cm long with the number of dowels corresponding to a tuber density of 45 tubers·m^{-2}. This density was chosen based on results from additive experiments that showed minimal increases in pepper fruit yield loss with increases in initial yellow nutsedge tuber densities above 45 tubers·m^{-2}.

Nutsedge 'Chufa' tubers were sprouted in the greenhouse in trays filled with potting soil (Fafard Mix No. 2; V-J Growers Supply; Apopka, Fla). When about 9 cm tall, after unfurling of three to four leaves surrounding the rhizome meristem, they were planted in the field. On the day bell pepper ('X3R Camelot') seedlings were transplanted (Table 2-1; same day holes were punched), nutsedge seedlings were planted in all plots in the removal experiment, except the weed-free check plots, and in five plots in the plant back study (season-long nutsedge interference treatment). Each nutsedge planting hole received one tuber and associated shoot(s). At 1, 3, 5, and 7 WAT, nutsedge plants were either planted or removed according to treatments. Removal of nutsedge was done by hand with care taken not to disturb pepper plants and the polyethylene mulch.

Drip irrigation with biwall tubing (orifice diameter, 0.025 cm; emitter spacing, 30 cm; flow rate of 1.89 L per 30.5 m per min) placed on the soil surface at the middle of

each bed simultaneously with polyethylene mulch application was used to supply water as needed to prevent moisture stress to plants. Irrigation times for each week were scheduled to apply approximately 75% of the mean daily volume of ET for the previous seven days.

The soil received 224:37:186 $kg \cdot ha^{-1}$ of N-P-K, respectively. In each season, all P and 40% of N and K were applied preplant-incorporated prior to mulch application. The remainder of N and K was drip-applied in 10 equal weekly applications each season. Pesticides were applied as needed for insect and disease control.

Measured and Derived Variables

During each season, measured variables included pepper and nutsedge plant height, pepper and nutsedge plant dry weight, nutsedge shoot number, and harvested pepper fruit weight. Pepper plant dry weight and harvested pepper fruit weights were converted to percent of weight obtained with pepper grown weed-free.

Pepper plant height, the distance from the bed surface to the highest bud, was measured at the same times as nutsedge was planted or removed (Table 2-1). Pepper height data were collected for four representative plants in the middle of each plot. A stake, placed in the ground at pepper flowering, was used to indicate the location of the four plants so that height data were collected from the same plants each time.

Nutsedge shoot height, the distance from the bed surface to the highest growing point of leaf blades, was measured at the same times as pepper plant heights (Table 2-1). Heights were obtained from eight leaf blades in the middle of each plot.

Nutsedge shoots were counted at one end of each plot in a 0.1 m^2 area surrounded by nutsedge and pepper plants (Table 2-1). Shoots were counted at the same times as

nutsedge was planted or removed. In each plot with nutsedge and at each time nutsedge was planted or removed, nutsedge shoots that were counted were immediately sampled by cutting at ground level and placed in a paper bag. These samples were dried at 60°C prior to obtaining dry weights.

One representative pepper plant from each end of every plot was sampled at the same times as nutsedge planting or removal (Table 2-1). Roots were removed from pepper plant stems, and each plant placed in a paper bag. Pepper plant samples were dried in the same manner as nutsedge plant samples.

Pepper fruits were harvested twice each season (Table 2-1). Weights were recorded for U.S. Fancy, U.S. No.1, and U.S. No. 2 fruit according to U.S. Dept. of Agriculture standards. Harvested pepper fruit weight data for each harvest were summed to obtain total fruit weight for each fruit size category. Large fruit yield was derived from the sum of U.S. Fancy and U.S. No. 1 fruit. Yields of U.S. Fancy, U.S. No. 1 and U.S. No. 2 fruit were summed to obtain marketable fruit yield. Total yield was the sum of yield for all fruit grades including culls. Harvested fruit yields were converted to percent of yield with pepper grown weed-free.

Data Analysis Procedures

Data were subjected to analysis of variance using SAS (SAS, 2000). Significant effects were obtained with F-tests. Pepper fruit yield and vegetative dry weight data were expressed in table format as actual values and as percent of values obtained with pepper grown weed-free. Pepper fruit and vegetative yield responses to nutsedge planting or removal time were described with polynomial contrasts. Interactions were indicated in tables, but further analysis of interactions was only performed on data analyzed as percent

of values obtained with pepper grown weed-free. Responses of harvested pepper fruit weight, end-of-season pepper plant dry weight, and end-of-season nutsedge shoot number and dry weight were regressed with a best-fit model. Responses of remaining variables to nutsedge planting or removal time were described with polynomial contrasts.

Results and Discussion

Removal Experiment

The treatment corresponding to the season-long weed-free check was the 0 WAT nutsedge removal time. This treatment is referred to below as "0 RT".

Pepper fruit yield

Large, marketable, and total fruit weights and percent of weight with pepper grown weed-free were at least 36% greater in spring than fall in 2000 (Table 2-2); however, season effects were contained in interactions discussed below. Study had no influence on large and marketable fruit weight percentages (of 0 RT).

Season interacted with study and nutsedge removal time on fruit weights ($t \cdot ha^{-1}$) and on total fruit weight percentage (of RT), but season only interacted with nutsedge removal time on large and marketable weight percentages (of 0 RT) (Figures 2-1 and 2-2). Percentages of large and marketable fruit weight obtained with pepper grown weed-free declined more rapidly in fall than spring with increases in nutsedge interference time.

According to a logistic model, spring-grown pepper tolerated about 2½ weeks of nutsedge interference by plants from 45 planted tubers$\cdot m^{-2}$ without a greater than 10% reduction in large fruit weight (Fig. 2-1). With a sigmoidal model, fall-season pepper tolerated less than 2 weeks of nutsedge interference without a reduction in large fruit weight of greater than 10%. With 5 weeks of nutsedge interference, large fruit weight

declined 90% in the fall compared to 70% in the spring. With 13 weeks of nutsedge interference, large fruit weight was reduced by 85% in the spring and over 95% in fall according to the models used.

With sigmoidal models, spring-grown pepper was shown to tolerate nearly 4 weeks while fall-grown pepper tolerated 1½ weeks of nutsedge interference without a reduction in marketable fruit weight of greater than 10% (Fig. 2-2). In both seasons, percentages of marketable fruit weight obtained with pepper grown weed-free were lowest and similar with 7 and 13 weeks of nutsedge interference. With 7 to 13 weeks of nutsedge interference, however, marketable fruit weights were about 30% and 5% of those produced without nutsedge interference in spring and fall, respectively.

As mentioned above, season, study, and nutsedge removal time interacted in their effects on total pepper fruit weight as percent of that obtained without nutsedge interference (Table 2-2; Fig. 2-3). In spring, there was little difference in the shape of slopes for each study. Spring-grown pepper plants in study A and B tolerated about 3½ and just over 3 weeks of nutsedge interference, respectively, without a reduction in total fruit weight of greater than 10%. In study A in fall, according to the model, pepper plants tolerated 2 weeks of nutsedge interference with a 10% reduction in total fruit weight loss. In study B in fall, however, 1 week of nutsedge interference resulted in about 15% total fruit weight reduction compared to weights obtained with pepper grown weed-free.

As shown by fruit production data, spring-season pepper tolerated yellow nutsedge interference longer than fall-grown pepper. This observation was consistent with that in the additive study (Chapter 1) where greater yield losses occurred in fall than spring seasons.

Declining pepper fruit yields with increased nutsedge interference time before nutsedge removal contrasted with results for fall-grown watermelon obtained by Buker III (1999) where yellow nutsedge interference times from 0 to 13 weeks after weed emergence did not appreciably reduce watermelon fruit production. In contrast to bell pepper, therefore, watermelon plants showed a capacity for recovery from the effects of nutsedge interference after nutsedge plants were removed.

Pepper plant height

Pepper plants at 1 and 3 WAT were taller in spring than fall (Table 2-3). At 1, 3, and 5 WAT plants grew to a similar height in study A as in study B; but season interacted with study on heights at 15/14 WAT because spring-grown pepper plants were taller in study A than B, whereas study did not affect fall-season pepper plant heights (Table 2-4).

Nutsedge interference vs. the absence of nutsedge did not affect pepper plant height at 1 and 3 WAT (Table 2-3). At 5 WAT, season interacted with nutsedge removal time on plant heights when nutsedge interference increased plant height in spring but had no affect on heights in fall (Table 2-5). In both seasons, pepper plant height increased slightly in a quadratic manner with an increase in nutsedge interference time from 1 to 5 weeks.

Season, study, and nutsedge removal time interacted in their effects on pepper plant height at 7 WAT (Tables 2-3 and 2-6). In both spring studies, pepper plants were taller with than without nutsedge interference, and plant heights increased quadratically with increased time that nutsedge interfered with pepper (Table 2-6). In both fall studies, nutsedge interference reduced pepper plant height compared to height of pepper plants

grown weed-free. In contrast to the spring studies, fall-season pepper plant heights declined linearly with an increase in nutsedge interference time from 1 to 7 WAT.

At the end of the spring and fall seasons, pepper plant heights were shorter with than without nutsedge interference and heights decreased quadratically from 42 cm with 1 week of interference to 40 cm with season-long interference (Table 2-3). Thus, height of pepper plants at the end of the season did not change appreciably with nutsedge removal time.

Responses of pepper plant height to nutsedge interference were similar to those in the additive study (Tables 1-6, 1-7, 1-8, and 1-9). In both the removal (Table 2-6) and additive studies (Tables 1-6, 1-7, and 1-9), nutsedge interference tended to increase pepper plant height in the spring while it reduced pepper plant height in the fall. In both experiments therefore, pepper plants competed more strongly with nutsedge for light in spring than fall seasons.

Pepper plant dry weight

Whole pepper plants (above-ground tissues) at 1 WAT weighed more in spring than fall, but dry weight percentages (of 0 RT) were similar between seasons (Table 2-7). At 3 WAT dry weights ($g \cdot plant^{-1}$) and weight percentages of (of 0 RT) were not influenced by season. At 5 and 7 WAT dry weight percentages (of 0 RT) were greater in spring than fall. At 14 WAT season interacted with study and removal time on dry weight (data not shown for $g \cdot plant^{-1}$), and season interacted with nutsedge removal time on dry weight percentage (of 0 RT) as discussed below.

At 1 WAT, dry weight of pepper plants in study B exceeded that of plants in study A, but there was no study effect with dry weights as percentages of the weed-free check

(Table 2-7). Study had no effect on dry weight of pepper plants sampled 3 WAT. Season interacted with study on weights ($g \cdot plant^{-1}$) of those sampled 5 and 7 WAT (data not shown) but not on dry weight percentages (of 0 RT) that were similar between studies at 5, 7, and 14 WAT.

One week of nutsedge interference had no effect on pepper plant growth (Table 2-7). From 3 to 5 WAT, pepper plant dry weights were greater for pepper plants grown weed-free than for those subjected to nutsedge interference. Dry weights ($g \cdot plant^{-1}$ and % of RT) of pepper plants sampled 3 WAT were significantly less with 3 than 1 week of nutsedge interference before nutsedge plants were removed. Dry weight ($g \cdot plant^{-1}$) of plants sampled 5 WAT declined linearly with an increase in nutsedge interference time from 1 to 5 weeks.

At 5, 7, and 14 WAT, season interacted with nutsedge removal time on pepper plant dry weight percentages (of 0 RT) because percentages (of 0 RT) decreased more sharply in fall than spring with increases in nutsedge interference time (Table 2-8; Fig. 2-4). Bell pepper tolerated about 1 and 2½ weeks of nutsedge interference in spring and fall, respectively, without a greater than 10% reduction in plant biomass (Fig. 2-4). This was likely an effect of declining nutsedge vigor over time in fall and increased nutsedge vigor with time in spring as explained in greater detail below.

These pepper plant biomass data showed that the competitive effects of yellow nutsedge on bell pepper were evident as early as 3 WAT. This observation was in agreement with the conclusion by William and Warren (1975) that purple nutsedge interference during the first third of the growing cycle for vegetable crops influenced subsequent crop growth and yield.

Nutsedge shoot height

Nutsedge shoot heights at 1 WAT were greater in the fall than spring (Table 2-9). At 1 WAT in the fall, nutsedge shoots were twice as tall as pepper seedlings (Table 2-3). Study had no influence on nutsedge shoot heights at 1 WAT (Table 2-9).

Season interacted with study on heights from 3 to 15/14 WAT (Tables 2-9 and 2-10). The main source of these interactions was that spring-season shoots were generally taller in study A than B (at 5, 7, and 15/14 WAT) while fall-season shoots were not affected by study (3 and 5 WAT) or were taller in study B than in A (7 and 15/14 WAT) (Table 2-10). At 3 and 5 WAT, shoot heights in each study were taller in fall than spring. These data and greater nutsedge shoot heights in fall than spring at 1 WAT accounted for reduced bell pepper tolerance of nutsedge in fall compared to spring (Figures 2-1, 2-2, 2-3, and 2-4) even though end-of-season shoot heights were greater in spring than fall (Table 2-10).

Nutsedge shoot number

At the 1st and 3rd WAT, nutsedge shoots were more numerous in fall than spring (Table 2-11), but were similar in both seasons at the 5th and 7th WAT. By the end of the season, spring-grown nutsedge shoots had proliferated to 163 shoots$\cdot$0.1m^{-2} compared to 56 shoots$\cdot$0.1m^{-2} in the fall. This was consistent with taller nutsedge shoot heights in spring than fall at the end of the season (Table 2-9). Shoot numbers were similar at all counting times in study A and B except at the 3rd WAT when shoots were more numerous in study B than A.

By the end of a growing season, a single sprouted tuber planted at the same time as pepper transplanting produced as many as 41 shoots. Tumbelson and Kommedahl

(1961) found that one yellow nutsedge tuber in the field produced an equivalent of 60 shoots in a 0.1 m^{-2} area. In the present study and in that by Tumbleson and Kommedahl (1961), therefore, yellow nutsedge was very prolific.

Nutsedge dry weight

Dry weights of nutsedge shoots sampled from a 0.1 m^{-2} area 1, 3, and 5 WAT were greater in fall than spring (Table 2-12). By 15/14 WAT, nutsedge shoot weights were greater in spring than fall plantings. Greater nutsedge growth and vigor at 1 WAT in fall than spring (Tables 2-9, 2-11, and 2-12) accounted for greater than 10% total bell pepper fruit yield loss in one of the fall-season studies with only 1 week of nutsedge interference before nutsedge removal (Fig 2-3).

Nutsedge shoots sampled 1 WAT in study A had more biomass than those in study B, but dry weights at 3 and 5 WAT were similar with both studies (Table 2-12). Season and study interacted on dry weight of shoots sampled 7 WAT because spring-season dry weights were greater in study A than B, whereas fall-season dry weights were greater in study B than A (Table 2-10).

Nutsedge Planting Time Experiment

In this experiment, the season-long weed-free check was the treatment where nutsedge was not planted during the 13-week long seasons (based on final fruit harvest time). This treatment is referred to as "13 PT" below.

Pepper fruit yield

Season effects on large, marketable, and total fruit yields were contained in interactions (Table 2-13) as explained below. Fruit weight percentages (of 13 PT) did not differ between studies. Season, study, and nutsedge planting time interacted on fruit

weights ($t \cdot ha^{-1}$), but season only interacted with nutsedge planting time on fruit weight percentages (of 13 PT) as shown in Figures 2-1, 2-2, and 2-3.

A nutsedge free time of approximately 5 (Figures 2-1 and 2-2) to 5½ (Fig. 2-3) weeks in spring compared to 6½ (Figures 2-2 and 2-3) to 7 (Fig. 2-1) weeks in fall was required to prevent pepper fruit yield losses of greater than 10% (of 13 PT). Season-long nutsedge interference reduced pepper fruit yields by 70% to 75% in spring compared to about 95% in fall (Figures 2-1, 2-2, and 2-3).

The critical yellow nutsedge-free period required for not greater than 10% reduction in large pepper fruit production was about 2½ to 5 and 1¾ to 7 WAT for a spring and fall crop, respectively (Fig 2-1). For not greater than 10% reduction of marketable fruit, a yellow nutsedge-free period of about 4 to 5 WAT was required in spring compared to approximately 1½ to 6½ WAT in the fall (Fig. 2-2). For total fruit yield in spring, a yellow-nutsedge-free period of about 3½ to 5½ WAT in study A and 3 to 5½ WAT in study B was required for not greater than 10% yield loss (Fig. 2-3). The critical nutsedge-free period for 10% loss of total yield of a fall crop was from 2 to 6½ WAT in study A and from 0 to 6½ WAT in study B. For all fruit grades, a longer nutsedge-free period was required for fall- than spring-grown pepper.

Morales-Payan (1999) found that, for marketable fruit yield of tomato, the critical yellow-nutsedge-free period was between 3 to 6 WAT. The critical weed-free period required for satisfactory fruit production was expected to be longer for bell pepper than tomato. This was the case for fall- but not spring-grown bell pepper. The ability of tomato vs. bell pepper to tolerate yellow nutsedge interference could also be determined by comparing fruit yield losses with season-long nutsedge interference at tuber densities

resulting in the biological threshold. Season-long nutsedge interference reduced marketable tomato fruit yields by 60% with 50 plants·m^{-2} (Morales-Payan, 1999) compared to a reduction of marketable bell pepper fruit of over 70% with nutsedge plants from 45 tubers·m^{-2} in the present experiment.

Yield losses of at least 70% (Figures 2-1, 2-2, and 2-3) with season-long yellow nutsedge interference in the nutsedge plant back and removal studies indicated that the critical yellow-nutsedge-free periods for spring- and fall-grown bell pepper were not underestimated. Yield losses with season-long nutsedge interference, in the plant back and removal experiments, were comparable to those obtained with the same initial nutsedge density (plants from 45 tubers·m^{-2}) in additive experiments conducted in spring and fall of 2000 (Fig. 1-3).

Pepper plant height

Pepper plants were taller in spring than fall at 1 and 3 WAT (Table 2-14). Season effects on heights from 5 to 15/14 WAT were influenced by interacting effects of study and/or nutsedge planting time as discussed below.

Pepper plant heights were similar in study A and B until the 5th WAT (Table 2-14). At the 5th and 15/14 WAT, season interacted with study on bell pepper plant heights. The primary source of these interactions was that spring-season pepper plants were taller in study A than B while fall-season pepper plants grew to similar heights in each study (Table 2-15).

Nutsedge interference did not affect pepper plant height at 1 and 3 WAT. (Table 2-14). At 5 WAT season interacted with nutsedge planting time on plant heights where nutsedge interference influenced the height of spring- but not fall-grown pepper plants

(Table 2-16). Spring-grown pepper plant heights decreased linearly while heights of fall-grown pepper plants decreased quadratically as nutsedge planting time was delayed from 1 to 5 WAT.

Season, study, and nutsedge planting time interacted in their effects on pepper plant heights at 7 WAT (Tables 2-14 and 2-17). In both spring studies, nutsedge interference (mean of 0 to 5 WAT) increased pepper plant height compared to heights with no nutsedge (7 WAT) (Table 2-17). Pepper plant heights in studies A and B decreased with an increase in weed-free time from 0 to 5 WAT before nutsedge was planted, but heights decreased more sharply in study A than B. In both fall studies, pepper plant heights were similar with (0 to 5 WAT) and without (7 WAT) nutsedge interference. Only in study A was pepper plant height differentially influenced by nutsedge free time. In this study, plant height increased in a cubic manner from 22 to 31 cm with an increase in nutsedge free time from 0 to 5 WAT. This increase in plant height with increases in nutsedge planting time delay indicated that, unlike in spring studies, nutsedge vigor was sufficient to hinder the ability of pepper plants to compete with nutsedge for light in fall studies.

At the end of the season (15/14 WAT), the main source of the season by nutsedge planting time interaction (Table 2-14) on pepper plant height at 15 (spring) or 14 (fall) WAT was that spring-season plant heights were similar while fall-season heights responded in cubic manner to increases in weed-free time from 1 to 15/14 WAT (Table 2-16). In both seasons, nutsedge interference had little or no influence on pepper plant height as compared to heights of pepper plants grown weed-free.

Pepper plant dry weight

Spring-grown pepper plants at 1 WAT weighed more than those in fall, but percent dry weight of pepper grown with no nutsedge did not vary with season at 1 and 3 WAT (Table 2-18). At 5, 7, and 14 WAT, dry weight percentages (of weed-free check) were greater in spring than fall. Study did not affect the growth of pepper plants expressed as percentages of dry weights with no nutsedge.

Yellow nutsedge planting time did not differentially influence pepper plant biomass until the 3rd WAT when plant dry weight percentages (of weed-free check) were less with nutsedge planted at 0 than 1 WAT (Table 2-18). At 5, 7, and 14 WAT dry weight percentages (of weed-free checks) increased the longer nutsedge planting time was delayed.

For 10% biomass reduction, a nutsedge-free period of about 1 to 6½ and 2¾ to 6½ WAT was required for the spring and fall crop, respectively (Fig. 2-4). Unlike with fruit yield (Figures 2-1, 2-2, and 2-3), a longer yellow nutsedge free period was required in fall than spring to prevent a greater than 10% reduction in pepper plant biomass (Fig. 2-4). This was accounted for by the decline in nutsedge vigor with time in fall allowing pepper plants to recover somewhat from nutsedge interference after nutsedge removal.

Nutsedge shoot height

Season effects on nutsedge shoot heights (Table 2-19) were contained in interactions explained below. Spring-season nutsedge reached a height of 68 cm by the end of the season while fall-grown nutsedge reached 55 cm at 7 WAT. By the end of the season, nutsedge shoots were laying over to a greater extent in fall than spring.

Season interacted with study on nutsedge shoot heights at 1 WAT (Table 2-19) when spring-grown shoots were taller in study A than B while fall-season shoot heights were similar between seasons (Table 2-20). Study had no affect on shoot heights at 3 WAT (Table 2-19). Shoots were taller in study A than B at 7 WAT. Season interacted with study on nutsedge shoot heights at 15/14 WAT when spring-grown nutsedge shoots were taller in study A than B while fall-season nutsedge shoots heights were taller in study B than A (Table 2-20).

Nutsedge planting time interacted with season and/or study on nutsedge shoot heights (Table 2-19). Season interacted with nutsedge planting time on nutsedge shoot heights at 3, 7 and 15/14 WAT (Tables 2-19 and 2-21). At 3 WAT, shoots of nutsedge planted 1 WAT were shorter than those planted at the same time as bell pepper, but there was a 3 cm difference in spring compared to an 11 cm difference in fall between shoot heights with the two nutsedge planting times (Table 2-21).

At 5 WAT, season, study, and planting time interacted in their effects on nutsedge shoot heights at 5 WAT (Tables 2-19 and 2-22). In spring studies, nutsedge shoot heights declined linearly with increased time before nutsedge planting, but heights decreased more sharply in study A than B (Table 2-22). In study A during the fall, shoots heights appeared similar with planting times of 0 and 1 WAT and then decreased with an increase in weed-free time from 1 to 3 WAT. In study B, shoot heights declined linearly with an increase in time from 0 to 3 WAT before nutsedge was planted.

At 7 WAT, shoot heights decreased linearly in the spring from 59 to 21 cm and quadratically in the fall from 66 to 29 cm with a delay in nutsedge planting from 0 to 5 WAT (Table 2-21). At 15 (spring)/14 (fall) WAT, both spring- and fall-season nutsedge

shoot height responses to nutsedge planting time were cubic, but there appeared to be greater variation among heights in spring than fall.

Study interacted with nutsedge planting time on nutsedge shoot heights at the end of the season (Tables 2-19 and 2-23). Shoot height responses to nutsedge planting time, in both studies, were cubic; but it appeared that shoots of nutsedge planted 1 and 3 WAT were taller in study A than B.

Nutsedge shoot number

Nutsedge plants produced more shoots in fall than spring at 1 WAT. In spring, shoot numbers increased from 8 shoots$\cdot$0.1m^{-2} at 1 WAT to 106 shoots$\cdot$0.1m^{-2} at 15/14 WAT. In fall, the increase in shoot number with time peaked at 71 shoots$\cdot$0.1m^{-2} at 7 WAT and then decreased to 27 shoots$\cdot$0.1m^{-2} by the end of the season. The low number of shoots at 14 WAT in fall (27) was due to shoot decline and death by the end of the season.

Study did not affect shoot number until the 3rd WAT (Table 2-24) during which season interacted with study and nutsedge planting time on shoot counts as explained below. At 5 WAT, shoots were more numerous in study A than B. At the 7th WAT and at the end of the season, season interacted with study on shoot numbers. In spring studies at 7 WAT, nutsedge shoots were more numerous in study A than B while shoot numbers were similar between studies in the fall (Table 2-20). At the end of the season, there were more spring-season shoots in study B than A while the number of fall-season shoots in both studies was similar.

Season, study, and nutsedge planting time interacted in their effects on nutsedge shoot number at the 3rd WAT (Tables 2-24 and 2-22). In study A in spring and B in fall,

nutsedge seedlings planted at the same time as pepper produced more shoots than those planted 1 WAT (Table 2-22). In study B in spring and A in fall, shoot numbers were similar with each nutsedge planting time.

Season interacted with nutsedge planting time on nutsedge shoot numbers at 5 WAT, (Tables 2-24 and 2-21). In spring, shoot number declined linearly from 84 to 22 shoots$\cdot$0.1 m^{-2} with an increase in the delay in nutsedge planting time from 0 to 3 WAT. In fall, shoot number declined quadratically from 97 to 18 shoots$\cdot$0.1 m^{-2} over the same nutsedge planting times.

At 7 WAT, nutsedge shoot numbers declined linearly from 123 to 15 shoots$\cdot$0.1 m^{-2} with an increase in nutsedge free time from 0 to 5 WAT before nutsedge planting (Table 2-24). At the end of the season, season interacted with nutsedge planting time on nutsedge shoot number (Table 2-24; Fig. 2-5). In spring, shoot numbers declined from over 160 to about 40 shoots$\cdot$0.1 m^{-2} with an increase in the delay in nutsedge planting time from 0 to 7 WAT (Fig. 2-5). In fall, shoot numbers were much lower than those in spring and declined from 50 to 15 shoots$\cdot$0.1 m^{-2} as the delay before nutsedge planting was increased from 0 to 7 WAT.

A single tuber planted with pepper produced 18 to 41 shoots by 15 or 14 WAT. Tumbleson and Kommedahl (1961) found, in a greenhouse study, that a single yellow nutsedge tuber produced 19 to 146 shoots depending on pot size and soil type. Thus, yellow nutsedge shoot proliferation can be quite variable.

Nutsedge shoot dry weight

Nutsedge shoot dry weights were greater in fall than spring at 1 WAT (Table 2-25). In spring, dry weights increased with time to 54 g$\cdot$0.1m^2 at the end of the season. In

fall, a maximum dry weight of 30 g·0.1m^2 was reached at 7 WAT instead of 14 WAT due to decreasing daylength and subsequent nutsedge vigor over time.

At 1 WAT, nutsedge shoots planted at the same time as pepper produced more biomass in study B than A (Table 2-25). Season interacted with study on nutsedge shoot dry weight at 7 WAT. In spring studies, shoot dry weight at 7 WAT was greater in study A than B but dry weights were similar with both studies in the fall (Tables 2-25 and 2-20). Shoot dry weights at 7 WAT were similar between seasons in study A, but were greater in fall than spring in study B. At the end of the season, there were no study effects on shoot dry weight (Table 2-25).

Nutsedge planting time influenced nutsedge shoot dry weights from 3 WAT to the end of the season (Table 2-25). At 3 WAT, season, study, and nutsedge planting time interacted in their effects on nutsedge shoot dry weight. Nutsedge dry weights at 3 WAT were consistently greater with nutsedge seedlings planted 0 than 1 WAT, but the decline in dry weight with an increase in the nutsedge planting time delay from 0 to 1 WAT was sharper in study A than B in spring and in study B than A in fall (Table 2-22).

At 5, 7, and 15/14 WAT, season interacted with nutsedge planting time on shoot dry weights (Table 2-25). At 5, 7, and 15/14 WAT, nutsedge shoot dry weights declined more sharply in fall than spring with increases in the time (WAT) before nutsedge was planted (Table 2-21; Fig. 2-6). At 5 and 7 WAT, study also interacted with nutsedge planting time on nutsedge shoot dry weight (Tables 2-25). At both sampling times, dry weights appeared to decline more sharply in study A than B (Table 2-23).

Values for nutsedge growth parameters were greater in fall than spring for the first 7 weeks of each season, but values were greater in spring than fall by the end of the

season due to a decline in nutsedge growth and vigor with time in the fall. Greater early-season (first 7 weeks) nutsedge vigor in fall than spring accounted for the longer weed-free time needed by the fall- than spring-grown pepper crop for acceptable growth (Fig. 2-4) and fruit yield (Figures 2-1, 2-2, and 2-3).

Values for nutsedge growth parameters declined with increases in the delay before nutsedge seedlings were planted. Shading of pepper by nutsedge likely decreased with an increase in time that pepper grew weed-free before nutsedge planting. This would explain increased pepper yield as nutsedge-free time was increased.

In both the plant back and removal study, nutsedge growth parameter data indicated that spring-grown nutsedge grew more vigorously in study A than B as explained for nutsedge growth parameters in the removal study. Nutsedge growth parameter data also indicated that fall-grown nutsedge grew more vigorously in study B than A. Although the soil types were the same in fall studies, soil in study B appeared slightly less sandy than in study A which may have increased nutsedge vigor. Yellow nutsedge was more prolific in clay vs. sandy soil in an experiment by Tumbleson and Kommedahl (1961).

Table 2-1. Dates for data collection events conducted at each yellow nutsedge planting or removal time as weeks after pepper transplanting (WAT).

	Dates corresponding to nutsedge planting times (WAT)					
Event	0	1	3	5	7	13
			Spring			
Planted pepper	23 Mar.	---	---	---	---	---
Removed/planted nutsedge	23 Mar.	30 Mar.	13 Apr.	27-28 Apr.	10-11 May	---
Measured plant ht[Z]	---	29 Mar.	12 Apr.	26 Apr.	9 May	5 July[Y]
Counted and sampled nutsedge shoots	---	30-31 Mar.	13-14 Apr.	27 Apr.	10 May	3 July[Y]
Sampled pepper	---	30-31 Mar.	13-14 Apr.	27 Apr.	9 May	30 June[Y]
First pepper harvest	---	---	---	---	---	9 June[Y]
Final pepper harvest	---	---	---	---	---	21 June[Y]
			Fall			
Planted pepper	16 Aug.	---	---	---	---	---
Removed/planted nutsedge	16 Aug.	23 Aug.	6 Sept.	20 Sept.	4 Oct.	---
Measured plant ht[z]	---	25 Aug.	7 Sept.	19 Sept.	3 Oct.	21 Nov.[Y]
Counted and sampled nutsedge shoots	---	24 Aug.	7-8 Sept.	19-20 Sept.	3 Oct.	21 Nov.[Y]
Sampled pepper	---	25 Aug.	8 Sept.	21 Sept.	5 Oct.	20 Nov.[Y]
First pepper harvest	---	---	---	---	---	6 Nov.[Y]
Final pepper harvest	---	---	---	---	---	15 Nov.[Y]

[Z]Pepper and yellow nutsedge heights were measured.

[Y]Final fruit harvest occurred at 13 WAT during both seasons, but initial pepper fruit harvest was conducted before 13 WAT with the remaining events conducted later than 13 WAT. In spring, nutsedge shoots were counted and sampled on 1 July.

Table 2-2. Main effects of season (2000), study, and yellow nutsedge removal time in weeks after pepper transplanting (WAT) on large, marketable, and total pepper fruit weight.

	Pepper fruit yield ($t \cdot ha^{-1}$ and % of check)					
	Large		Marketable		Total	
Treatment	$t \cdot ha^{-1}$	%[Z]	$t \cdot ha^{-1}$	%	$t \cdot ha^{-1}$	%
Season (S)						
Spring	22.97	61	25.25	63	31.63	62
Fall	11.77	33	16.04	36	18.17	39
Study (SY)						
A	20.35	50	22.69	51	27.83	52
B	14.38	44	18.60	48	21.96	50
Signif.		NS		NS		
Nutsedge removal						
0	30.70	-	35.61	-	41.60	-
1	28.45	96	33.43	95	38.90	95
3	24.45	78	28.92	81	34.47	82
5	10.87	33	14.20	39	18.94	43
7	4.91	15	6.42	17	9.31	20
13	4.82	15	5.30	15	6.17	14
S X RT		***		***		
S X SY X RT	***	NS	***	NS	***	**

[Z]Values were expressed as percent of those obtained with pepper grown weed-free for the duration of the season (0 RT).

[NS, **, ***]Main effects and interactions were nonsignificant or significant at $P \leq 0.01$ or 0.001, respectively, according to F tests.

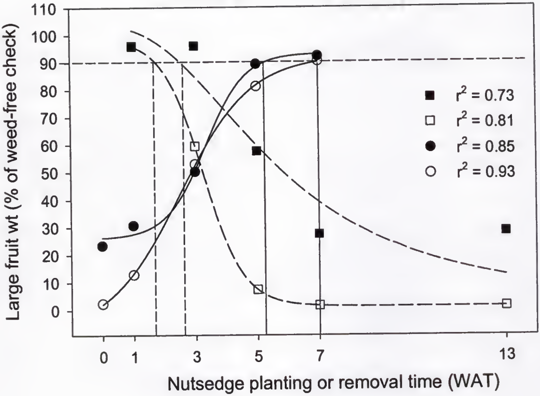


Fig. 2-1. Interaction of season (2000) and yellow nutsedge removal (----) or planting (—) time (weeks after pepper transplanting; WAT) on large pepper fruit weight. Data within means (shown) were regressed with a sigmoidal or logistic model. Equations for the nutsedge removal experiment were $Y = 103.3/(1 + (X/5.70)^{2.39})$ and $Y = 1.37 + 97.3/(1 + e^{(-(X - 3.25)/-0.645)})$ in spring (■) and fall (❑), respectively. Equations for the nutsedge planting experiment were $Y = 25.9 + 67.2/(1 + e^{(-(X - 3.34)/0.642)})$ and $Y = -8.14 + 100.2/(1 + e^{(-(X - 2.50)/1.16)})$ in spring (●) and fall (○), respectively. Models were significant at $P \leq 0.001$.

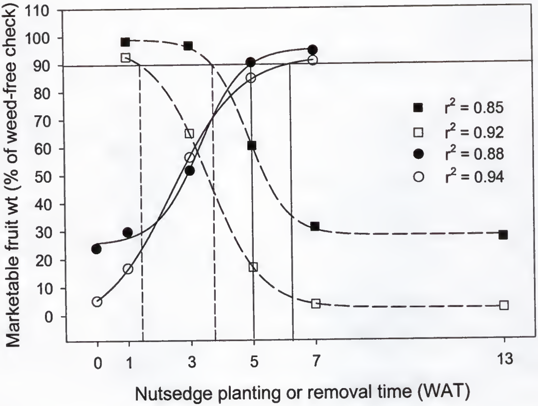


Fig. 2-2. Interaction of season (2000) and yellow nutsedge removal (----) or planting (—) time (weeks after pepper transplanting; WAT) on marketable pepper fruit weight. Data within means (shown) were regressed with a sigmoidal model. Equations for the nutsedge removal experiment were $Y = 28.2 + 70.7/(1 + e^{(-(X - 4.90)/0.609)})$ and $Y = 2.21 + 94.6/(1 + e^{(-(X - 3.57)/-0.843)})$ in spring (■) and fall (□), respectively. Equations for the nutsedge planting experiment were $Y = 25.3 + 70.2/(1 + e^{(-(X - 3.33)/0.691)})$ and $Y = -3.83 + 96.4/(1 + e^{(-(X - 2.44)/1.08)})$ in spring (●) and fall (○), respectively. Models were significant at $P \leq 0.001$.

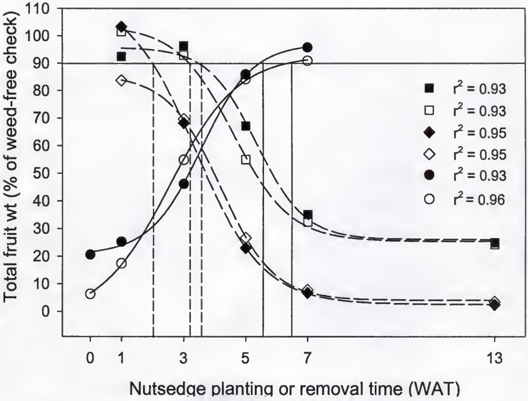


Fig. 2-3. Interaction of season (2000), study, and yellow nutsedge removal (----) and of season and nutsedge planting (—) time (weeks after pepper transplanting; WAT) on total pepper fruit weight. Data within means (shown) were regressed with a sigmoidal model. Equations for the nutsedge removal experiment in spring in study A(■) and B (❑), respectively, were $Y = 26.0 + 69.8/(1 + e^{(-(X - 5.34)/0.782)})$ and $Y = 25.4 + 78.2/(1 + e^{(-(X - 4.59)/-0.917)})$. Equations for nutsedge removal experiment in fall in study A (◆) and B (◇), respectively, were $Y = 2.54 + 112.2/(1 + e^{(-(X - 3.37)/-1.09)})$ and $Y = 4.04 + 81.7/(1 + e^{(-(X - 4.19)/-0.857)})$. Equations for the nutsedge planting experiment were $Y = 20.5 + 76.6/(1 + e^{(-(X - 3.56)0.834)})$ and $Y = -2.23 + 95.0/(1 + e^{(-(X - 2.53)/1.11)})$ in spring (●) and fall (O), respectively. Models were significant at $P \leq 0.001$.

Table 2-3. Main effects of season (2000), study, and yellow nutsedge removal time (RT) on bell pepper plant height at 1, 3, 5, 7, and 15/14 weeks after pepper transplanting (WAT).

	Pepper ht (cm) at WAT				
Treatment	1	3	5	7	15/14
Season (S)					
Spring	11	13	20	30	48
Fall	8	12	18	27	31
Signif.	***	***			
Study (SY)					
A	9	12	19	29	43
B	9	12	19	27	37
Signif.	NS	NS	NS		
S X SY	NS	NS	NS		***
Nutsedge RT (WAT)					
0	9	12	19	30	42
1	9	12	18	29	42
3	---	13	18	27	40
5	---	---	20	27	39
7	---	---	---	29	36
13	---	---	---	---	40
Check vs. nutsedge	NS	NS			*
Nutsedge	---	***			Q***
S X RT	NS	NS	***		NS
S X SY X RT	NS	NS	NS	**	NS

[z]End-of-season pepper plant heights were measured at 15 and 14 WAT in spring and fall, respectively. For analysis of variance, nutsedge removal times of 1, 3, 5, 7, and 13 WAT were used as final pepper harvest occurred at 13 WAT during both seasons.

[NS, *, **, ***]Effects were nonsignificant or significant at $P \leq 0.05, 0.01$, or 0.001, respectively, according to F tests. Competition (1 to 13 RT) vs. no competition (0 RT) effects were tested with contrasts. Nutsedge removal time (1 to 13 WAT) effect at 15/14 WAT was (Q) according to a polynomial contrast.

Table 2-4. Interaction of season (2000) and study on bell pepper plant height at the end of the seasons in the yellow nutsedge removal experiment.

	Study		
Season	A	B	Signif.
	Pepper plant ht (cm)		
Spring	54	42	***
Fall	31	32	NS
Signif.	***	***	

NS, ***Column and row effects were nonsignificant or significant at $P \le 0.001$ according to F-tests.

Table 2-5. Interaction of season (2000) and yellow nutsedge removal time (weeks after pepper transplanting; WAT) on bell pepper plant height at 5 WAT.

	Nutsedge removal time (WAT)					
	0	1	3	5		
Season	Pepper plant ht (cm)				Nutsedge vs. check[Z]	Nutsedge
Spring	19	19	19	22	**	Q***
Fall	19	17	17	18	NS	Q*

[Z]Nutsedge removed 0 WAT was the weed-free check. Competition (RT from 1 to 5 WAT) vs. no competition (check) was tested with contrasts.

NS, *, **, ***Effects were nonsignificant or significant at $P \le 0.05$, 0.01, or 0.001 according to F-tests. Nutsedge removal time (1 to 5 WAT) effects were quadratic (Q) according to polynomial contrasts.

Table 2-6. Interaction of season (2000), study, and yellow nutsedge removal time on bell pepper plant height at seven weeks after pepper transplanting (WAT).

		Nutsedge removal time (WAT)						
		0	1	3	5	7		
Season	Study	Pepper plant ht (cm)					Nutsedge vs. check[Z]	Nutsedge
Spring	A	30	30	29	34	40	**	Q***
Spring	B	25	25	26	28	31	*	Q*
Fall	A	31	30	25	22	21	***	L***
Fall	B	31	30	27	23	26	**	L**

[Z]Nutsedge planted 0 WAT was the weed-free check. Competition (1 to 7 WAT) vs no competition (0 WAT) effects were tested with contrasts.

*, **, ***Effects were significant at $P \leq 0.05$, 0.01, or 0.001 according to F-tests. Nutsedge removal time (1 to 7 WAT) effects were linear (L) or quadratic (Q) according to polynomial contrasts.

Table 2-7. Main effects of season (2000), study, and yellow nutsedge removal time (RT) on dry weight of bell pepper plants sampled at 1, 3, 5, 7, and 14 weeks after pepper transplanting (WAT).

	Pepper dry wt (g·plant^{-1} and % of check) at WAT									
	1		3		5		7		14	
Treatment	g	%[z]	g	%	g	%	g	%	g	%
Season (S)										
Spring	0.20	101	0.73	90	3.85	79	11.5	70	31.5	58
Fall	0.15	100	0.63	69	2.59	48	7.4	39	13.4	66
Signif.	***	NS	NS	NS		***		***		
Study (SY)										
A	0.16	101	0.68	79	3.64	65	10.9	55	25.0	58
B	0.20	100	0.68	79	2.80	62	8.0	55	19.9	66
Signif.	**	NS	NS	NS		NS		NS		NS
S X SY	NS	NS	NS	NS	**	NS	**	NS		NS
Nutsedge RT (WAT)										
0	0.18	---	0.85	---	4.46	---	14.9	---	32.8	---
1	0.18	101	0.67	88	3.96	89	13.2	88	30.9	97
3	---	---	0.53	70	2.68	61	9.0	63	26.6	84
5	---	---	---	---	1.77	40	5.7	39	20.1	59
7	---	---	---	---	---	---	4.3	29	16.1	47
13	---	---	-	---	---	---	---	---	8.4	24
Check vs. nutsedge	NS	---	**	---	***	---		---		---
Nutsedge	---	---	**	**	L***					
S X RT	NS	---	NS	NS	NS	**	**	*		***
SXSYXRT	NS	---	NS	NS	NS	NS	NS	NS	*	NS

[z]Values were expressed as percent of those with the weed-free check (0 WAT).

NS, *, **, ***Main effects were nonsignificant or significant at $P \leq 0.1$, 0.05, 0.01, or 0.001, respectively, according to F tests. Competition (1 to 13 WAT) vs. no competition (0 WAT) effects were tested with contrasts. Nutsedge removal time effect at 5 WAT was linear (L) according to a polynomial contrast.

Table 2-8. Interaction of season (2000) and yellow nutsedge removal time on dry weight per plant of bell pepper plants sampled 5, 7, and 14 weeks after pepper transplanting (WAT).

	Nutsedge removal time (WAT)					
Season	1	3	5	7	13	Signif.
			Pepper dry wt at 5 WAT (% of check)[z]			
Spring	96	81	59	---	---	L***
Fall	82	41	22	---	---	Q*
			Pepper dry wt at 7 WAT (% of check)			
Spring	97	84	55	46	---	C*
Fall	80	42	22	13	---	Q**
			Pepper dry wt at 14 WAT (% of check)			
Spring	90	81	69	60	29	L***
Fall	103	86	48	33	19	Q***

[z]Values were converted to percent of those with the weed-free check (0 WAT).

*, **, ***Effects were significant at $P \leq 0.05$, 0.01, or 0.001 according to F-tests. Nutsedge removal time effects were linear (L), quadratic (Q), or cubic (C) according to polynomial contrasts.

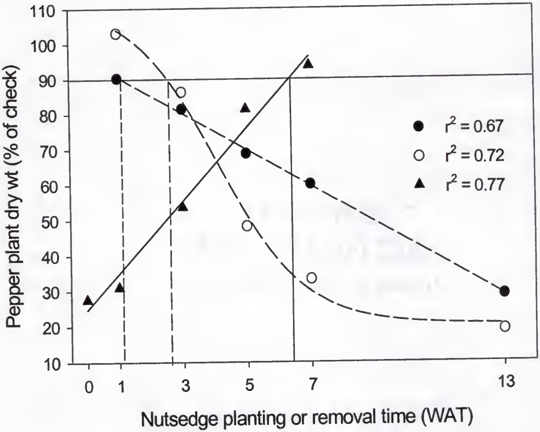


Fig. 2-4. Interaction of season (2000) and yellow nutsedge removal (----) time and main effect of nutsedge planting (—) time on end-of-season pepper plant dry weight as percent of that obtained with pepper grown weed-free. Data within means (shown) were regressed with a linear or sigmoidal model. Equations for the nutsedge removal experiment were Y = 9.6 - 5.16(X) and $Y = 20.3 + 92.0/(1 + e^{(-(X - 4.10)/-1.34)})$ in spring (●) and fall (○), respectively, . The equation for the nutsedge planting experiment (▲) was Y = 24.7 + 10.2(X). Models were significant at $P \leq 0.001$.

Table 2-9. Main effects of season (2000) and study on yellow nutsedge shoot height at 1, 3, 5, 7, and 15/14 weeks after pepper transplanting (WAT).

	Nutsedge ht (cm) at WAT				
Treatment	1	3	5	7	15/14[Z]
Season (S)					
Spring	11	22	34	63	72
Fall	16	41	60	66	45
Signif.	***				
Study (SY)					
A	13	31	47	66	60
B	14	31	47	64	58
Signif.	NS				
S X SY	NS	*	***	***	***

[Z]End-of-season nutsedge shoot heights were measured at 15 and 14 WAT in spring and fall, respectively.

[NS, *, ***]Effects were nonsignificant or significant at $P \leq 0.05$ or 0.001, respectively, according to F tests.

Table 2-10. Interaction of season (2000) and study on yellow nutsedge shoot height at 3, 5, 7, and 15/14 weeks after pepper transplanting (WAT) and on yellow nutsedge shoot dry weight at 7 WAT in the nutsedge removal experiment.

	Study		
Season	A	B	Signif.
	Nutsedge ht 3 WAT (cm)		
Spring	23	21	NS
Fall	40	42	NS
Signif.	***	***	
	Nutsedge ht 5 WAT (cm)		
Spring	37	31	***
Fall	58	62	NS
Signif.	***	***	
	Nutsedge ht 7 WAT (cm)		
Spring	67	59	***
Fall	65	68	*
Signif.	NS	***	
	Nutsedge ht 15/14[Z] WAT (cm)		
Spring	79	65	**
Fall	41	50	**
Signif.	***	***	
	Nusedge dry wt 7 WAT ($g \cdot 0.1 m^{-2}$)		
Spring	55.2	37.8	**
Fall	49.4	65.8	**
Signif.	NS	***	

[Z]End-of-season nutsedge shoot heights were obtained 15 and 14 WAT in spring and fall, respectively.

[NS, *, **, ***]Row and column effects were nonsignificant or significant at $P \leq 0.05$, 0.01, and 0.001, respectively, according to F-tests.

Table 2-11. Main effects of season (2000) and study on yellow nutsedge shoot number at 1, 3, 5, 7, and 15/14 weeks after pepper transplanting (WAT) in the nutsedge removal experiment.

	Nutsedge shoot no. (no.$\cdot$0.1m^{-2}) at WAT				
Treatment	1	3	5	7	15/14^{Z}
Season					
Spring	7	31	106	126	163
Fall	12	54	102	107	56
Signif.	***	***	NS	NS	***
Study					
A	9	37	99	122	116
B	10	47	110	112	104
Signif.	NS	*	NS	NS	NS

^{Z}End-of-season nutsedge shoot counts were obtained 15 and 14 WAT in spring and fall, respectively.

$^{NS, *, ***}$Effects were nonsignificant or significant at $P \leq 0.05$ or 0.001, respectively, according to F tests.

Table 2-12. Main effects of season (2000) and study on yellow nutsedge shoot dry weight at 1, 3, 5, 7, and 15/14 weeks after pepper transplanting (WAT) in the nutsedge removal experiment.

	Nutsedge shoot dry wt ($g.\cdot 0.1m^{-2}$) at WAT				
Treatment	1	3	5	7	15/14[Z]
Season (S)					
Spring	0.32	3.50	22.97	46.5	95.0
Fall	0.84	15.87	37.00	57.6	48.4
Signif.	***	***	***		***
Study (SY)					
A	0.52	9.79	30.28	52.3	73.1
B	0.64	9.58	29.70	51.8	70.3
Signif.	**	NS	NS		NS
S X SY	NS	NS	NS	***	NS

[Z]End-of-season nutsedge shoots were sampled at 15 and 14 WAT in spring and fall, respectively.

[NS, **, ***]Effects were nonsignificant or significant at $P \leq 0.01$ or 0.001, respectively, according to F tests.

Table 2-13. Main effects of season (2000), study, and yellow nutsedge planting time in weeks after pepper transplanting (WAT) on large, marketable, and total bell pepper fruit weights.

	Pepper fruit yield (t·ha^{-1} and % of check)					
	Large		Marketable		Total	
Treatment	t·ha^{-1}	%^{Z}	t·ha^{-1}	%	t·ha^{-1}	%
Season (S)						
Spring	22.25	57	23.93	58	29.04	55
Fall	15.02	48	19.65	51	20.79	51
Study (SY)						
A	22.38	53	25.19	55	29.22	54
B	14.88	52	18.40	54	20.60	51
Signif.		NS		NS		NS
Nutsedge planting time (PT; WAT)						
0	4.41	13	5.29	15	6.02	13
1	6.98	22	8.24	23	8.95	21
3	16.01	52	19.06	54	20.82	50
5	25.97	85	30.49	88	34.64	85
7	27.74	91	32.38	93	38.12	93
13	30.69	---	35.30	---	40.92	---
S X PT		**		***		***
SY X PT		NS		NS		NS
S X SY X PT	**	NS	***	NS	***	NS

^{Z}Values were expressed as percent of those obtained with pepper grown weed-free for the duration of the season (13 PT).

$^{NS, **, ***}$Main effects and interactions were nonsignificant or significant at $P \leq 0.01$ or 0.001, respectively, according to F tests.

Table 2-14. Main effects of season (2000), study, and yellow nutsedge planting time on height of bell pepper plants at 1, 3, 5, 7, and 15/14 weeks after pepper transplanting (WAT).

	Plant ht (cm) at WAT				
Treatment	1	3	5	7	15/14[Z]
Season (S)					
Spring	11	13	20	30	48
Fall	8	12	20	30	35
Signif.	***	*			
Study (SY)					
A	9	13	20	31	45
B	9	12	19	28	38
Signif.	NS	NS			
S X SY	NS	NS	**		***
Nutsedge planting time (PT; WAT)					
0	9	13	20	30	42
1	9	13	21	32	43
3	-	12	19	29	41
5	-	-	18	29	42
7	-	-	-	28	40
13	-	-	-	-	41
Check vs. nutsedge[Y]	NS	NS			
Nutsedge	-	NS			
S X PT	NS	NS	**		*
S X SY X PT	NS	NS	NS	***	NS

[Z]End-of-season pepper plant heights were measured at 15 and 14 WAT in spring and fall, respectively.

[Y]For 1, 3, 5, 7, and 15/14 WAT, the weed-free check was the 1, 3, 5, 7, and 13 PT treatment, respectively. Nutsedge vs. no competition effects were tested with contrasts.

[NS, *, **, ***]Effects were nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively, according to F tests.

Table 2-15. Interaction of season (2000) and study on pepper height five and 15/14 weeks after pepper transplanting (WAT) in the nutsedge plant back experiment.

	Study		
Season	A	B	Signif.
	Pepper plant ht 5 WAT (cm)		
Spring	21	19	***
Fall	19	20	NS
	***	*	
	Pepper plant ht 15/14^{Z} WAT (cm)		
Spring	55	40	***
Fall	35	35	NS
	***	**	

^{Z}End-of-season pepper plant heights were obtained 15 and 14 WAT in spring and fall, respectively.

$^{NS, *, **, ***}$Column and row effects were nonsignificant or significant at P ≤ 0.05, 0.01, or 0.001 according to F-tests.

Table 2-16. Interaction of season (2000) and yellow nutsedge planting time on bell pepper plant height five weeks after pepper transplanting (WAT) and at the end of the season.

	Nutsedge planting time (WAT)							
Season	0	1	3	5	7	13	Nutsedge vs. check[Y]	Nutsedge
	Pepper plant ht 5 WAT (cm)							
Spring	22	20	19	19	---	---	**	L***
Fall	19	22	18	19	---	---	NS	Q**
	Pepper plant ht 15/14[Z] WAT (cm)							
Spring	50	49	45	48	47	47	NS	NS
Fall	34	37	37	35	33	34	NS	C**

[Z]End-of-season pepper plant heights were obtained at 15 and 14 WAT in spring and fall, respectively.

[Y]Weed-free checks were the 5 and 13 WAT planting time treatments, respectively, for heights obtained at 5 and 15/14 WAT. Nutsedge vs. no nutsedge (check) effects were tested with contrasts.

[NS, **, ***]Effects were nonsignificant or significant at $P \leq 0.01$ or 0.001 according to F-tests. Significant nutsedge planting time (0 to 3 or 0 to 7 WAT) effects were linear (L) or cubic (C) according to polynomial contrasts.

Table 2-17. Interaction of season (2000), study, and yellow nutsedge planting time on bell pepper plant height at seven weeks after pepper transplanting (WAT).

		Nutsedge planting time (WAT)						
Season	Study	0	1	3	5	7	Nutsedge vs. check[Z]	Nutsedge
		Pepper plant ht (cm)						
Spring	A	40	35	29	30	30	***	C**
Spring	B	28	28	24	26	25	*	L**
Fall	A	22	33	33	31	30	NS	C**
Fall	B	29	33	29	31	29	NS	NS

[Z]Nutsedge planted 7 WAT was the weed-free check. Competition (0 to 5 PT) vs. no competition (check) effects were tested with contrasts.

[NS, *, **, ***]Effects were nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001 according to F-tests. Significant nutsedge planting time (0 to 5 WAT) effects were linear (L) or cubic (C) according to polynomial contrasts.

Table 2-18. Main effects of season (2000), study, and yellow nutsedge planting time (PT) on dry weight of pepper plants at 1, 3, 5, 7, and 14 weeks after pepper transplanting (WAT).

	Pepper dry wt (g·plant^{-1} and % of check) at WAT									
Treatment	1		3		5		7		14	
	g	%^{Z}	g	%	g	%	g	%	g	%
Season (S)										
Spring	0.21	99	0.68	95	3.51	80	10.8	70	23.1	65
Fall	0.17	99	0.77	75	2.38	44	7.67	50	13.5	50
Signif.	***	NS		NS		***		***		***
Study (SY)										
A	0.19	98	0.73	80	3.45	61	10.8	57	22.5	57
B	0.20	100	0.71	89	2.44	63	7.65	63	14.2	58
Signif.	NS	NS		NS		NS		NS		NS
S X SY	NS	NS	**	NS	**	NS		NS		NS
Nutsedge PT (WAT)										
0	0.19	99	0.60	77	1.79	44	4.07	30	8.16	28
1	0.19	---	0.74	93	2.47	65	5.69	41	9.01	31
3	---	---	0.83	---	3.35	87	9.77	73	15.0	54
5	---	---	---	---	3.88	---	12.9	95	23.5	81
7	---	---	---	---	---	---	13.8	---	26.4	94
13	---	---	---	---	---	---	---	---	28.1	---
Check vs. nutsedge	NS	---		---		---		---		---
Nutsedge	---	---		**		L***		L***		C***
S X PT	NS	—	*	NS	*	NS		NS		NS
SXSYXPT	NS	---	NS	NS	NS	NS	***	NS	***	NS

^{Z}Values were expressed as percent of the weed-free check (1, 3, 5, 7, and 13 WAT for pepper plants sampled at 1, 3, 5, 7, and 14 WAT, respectively).

$^{NS, *, **, ***}$Effects were nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively, according to F tests. Nutsedge vs. no nutsedge (check) effects were tested with contrasts. Planting time (excluding the check for each sampling time) effects were linear (L) or cubic (C) according to polynomial contrasts.

Table 2-19. Main effects of season (2000), study, and yellow nutsedge planting time on nutsedge shoot height at 1, 3, 5, 7, and 15/14 weeks after pepper transplanting (WAT).

	Nutsedge ht (cm) at WAT				
Treatment	1	3	5	7	15/14[Z]
Season (S)					
Spring	11	20	25	43	68
Fall	18	31	44	55	40
Study (SY)					
A	14	26	36	50	55
B	15	26	33	47	53
Signif.		NS		***	
S X SY	**	NS		NS	***
Nutsedge planting time (PT; WAT)					
0	15	29	46	63	57
1	---	22	38	60	57
3	---	---	18	47	59
5	---	---	---	25	52
7	---	---	---	---	45
S X PT	---	***		***	***
SY X PT	--	NS		NS	*
S X SY X PT	---	NS	**	NS	NS

[Z]End-of-season nutsedge shoot heights were measured at 15 and 14 WAT in spring and fall, respectively.

NS, *, **, ***Main effects were nonsignificant or significant at P ≤ 0.05, 0.01, or 0.001, respectively, according to F tests.

Table 2-20. Interaction of season (2000) and study on yellow nutsedge shoot height 1, 5, and 15/14 weeks after pepper transplanting (WAT), shoot number 7 and 15/14 WAT, and shoot dry weight 7 WAT in the plant back experiment.

Season	Study A	Study B	Signif.
	Nutsedge ht 1 WAT (cm)		
Spring	11	10	*
Fall	17	20	NS
	***	***	
	Nutsedge ht 15/14[Z] WAT (cm)		
Spring	71	66	**
Fall	39	41	**
	***	***	
	Nutsedge no. 7 WAT (no.·0.1 m^{-2})		
Spring	89	62	**
Fall	71	71	NS
	*	NS	
	Nutsedge no. 15/14[Z] WAT (no.·0.1 m^{-2})		
Spring	97	116	*
Fall	26	27	NS
	***	***	
	Nutsedge dry wt 7 WAT (g·0.1 m^{-2})		
Spring	26	19	**
Fall	29	31	NS
	NS	**	

[Z]Data were obtained at 15 and 14 WAT in spring and fall, respectively.

[NS, *, **, ***]Column and row effects were nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively, according to F-tests.

Table 2-21. Interaction of season (2000) and yellow nutsedge planting time on nutsedge shoot height, number, and dry weight at varying nutsedge planting times.

	Nutsedge planting time [(weeks after pepper transplanting (WAT)]					
Season	0	1	3	5	7	Signif.
			Nutsedge ht 3 WAT (cm)			
Spring	22	19	---	---	---	***
Fall	37	26	---	---	---	***
			Nutsedge ht 7 WAT (cm)			
Spring	59	52	39	21	---	L***
Fall	66	68	56	29	---	Q***
			Nutsedge ht 15/14[Z] WAT (cm)			
Spring	56	60	61	51	44	C**
Fall	57	55	57	54	44	C*
			Nutsedge no. 5 WAT ($no.\cdot 0.1\ m^{-2}$)			
Spring	84	67	22	---	---	L***
Fall	97	50	18	---	---	Q**
			Nutsedge dry wt 5 WAT ($g\cdot 0.1\ m^{-2}$)			
Spring	17	11	2	---	---	L***
Fall	41	20	2	---	---	Q**
			Nutsedge dry wt 7 WAT ($g\cdot 0.1\ m^{-2}$)			
Spring	44	33	12	0.8	---	Q*
Fall	61	43	15	1.9	---	Q**

[Z]Data were collected at 15 and 14 WAT in spring and fall, respectively.

[NS, *, **, ***]Effects were nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively, according to F-tests. Nutsedge planting time effects for data taken 5, 7, or 15/14 WAT were (L), quadratic (Q), or cubic according to polynomial contrasts.

Table 2-22. Interaction of season (2000), study, and yellow nutsedge planting time on nutsedge shoot height at 5 weeks after pepper transplanting (WAT), shoot number at 3 WAT, and shoot dry weight at 3 WAT.

		Nutsedge planting time (WAT)			
Season	Study	0	1	3	Signif.
		Nutsedge ht 5 WAT (cm)			
Spring	A	37	31	18	L***
Spring	B	27	23	15	L***
Fall	A	58	51	20	Q*
Fall	B	63	49	21	L***
		Nutsedge no. 3 WAT ($no.\cdot 0.1m^{-2}$)			
Spring	A	35	20	---	**
Spring	B	28	24	---	NS
Fall	A	29	23	---	NS
Fall	B	62	29	---	**
		Nutsedge dry wt 3 WAT ($g\cdot 0.1m^{-2}$)			
Spring	A	3.90	1.28	---	*
Spring	B	2.48	1.46	---	*
Fall	A	8.13	4.95	---	*
Fall	B	15.0	3.50	---	***

NS, *, **, ***Effects were nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively, according to F-tests. Nutsedge planting time effects on shoot height at 5 WAT were linear (L) or quadratic (Q) according to polynomial contrasts.

Table 2-23. Interaction of study and yellow nutsedge planting time on nutsedge shoot height 15/14 weeks after pepper transplanting (WAT) and dry weight 5 and 7 (WAT).

	Nutsedge planting time (WAT)					
Study	0	1	3	5	7	Signif.
			Nutsedge ht 15/14[z] WAT (cm)			
A	57	60	61	51	45	C*
B	57	55	57	54	45	C*
			Nutsedge dry wt 5 WAT ($g \cdot 0.1\ m^{-2}$)			
A	36	20	2.5	---	---	Q**
B	22	10	1.3	---	---	Q**
			Nutsedge dry wt 7 WAT ($g \cdot 0.1\ m^{-2}$)			
A	58	27	16	1.5	---	Q***
B	47	39	11	1.2	---	Q*

[z]Data were collected at 15 and 14 WAT in spring and fall, respectively.

*, **, ***Effects were significant at $P \leq 0.05$, 0.01, or 0.001, respectively, according to F-tests. Nutsedge planting time effects were quadratic (Q) or cubic (C) according to polynomial contrasts.

Table 2-24. Main effects of season (2000), study, and yellow nutsedge planting time on nutsedge shoot number at 1, 3, 5, 7, and 15/14 weeks after pepper transplanting (WAT).

	Nutsedge shoots (no.·$0.1m^{-2}$) at WAT				
Treatment	1	3	5	7	15/14[Z]
Season (S)					
Spring	8	27	58	75	106
Fall	10	36	55	71	27
Signif.	**				
Study (SY)					
A	8	27	65	80	62
B	10	36	48	67	71
Signif.	NS		***		
S X SY	NS		NS	**	*
Nutsedge planting time (PT; WAT)					
0	9	38	90	123	106
1	---	24	58	99	83
3	---	---	20	57	72
5	---	---	---	15	48
7	---	---	---	---	24
Signif.	---			L***	
S X PT	---		**	NS	***
SY X PT	---		NS	NS	NS
S X SY X PT	---	***	NS	NS	NS

[Z]End-of-season nutsedge shoot counts were obtained from plants sampled 15 and 14 WAT in spring and fall, respectively.

[NS, *, **, ***]Main effects were nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively, according to F tests. Planting time effect at 7 WAT was linear (L) according to a polynomial contrasts.

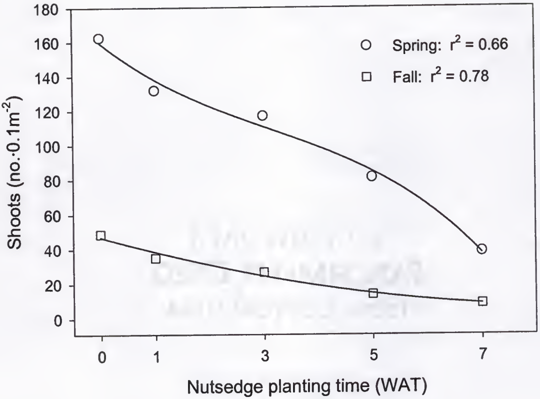


Fig. 2-5. Interaction of season (2000) and yellow nutsedge planting time on end-of season nutsedge shoot number. Data within means (shown) were regressed with a cubic or quadratic model in spring and fall, respectively. Equations were $Y = 159.7 - 25.7(X) + 4.60(X^2) - 0.487(X^3)$ and $Y = 47.0 - 8.91(X) + 0.492(X^2)$ for spring (○) and fall (□), respectively.

Table 2-25. Main effects of season, study, and yellow nutsedge planting time on nutsedge shoot dry weight at 1, 3, 5, 7, and 15/14 weeks after pepper transplanting (WAT).

	Nutsedge dry wt ($g \cdot 0.1m^{-2}$) at WAT				
Treatment	1	3	5	7	15/14[z]
Season (S)					
Spring	0.44	2.29	9.92	22.3	53.9
Fall	0.64	7.90	21.12	29.9	22.3
Signif.	**				
Study (SY)					
A	0.44	4.57	19.77	27.7	37.7
B	0.63	5.61	11.27	24.5	38.4
Signif.	**				NS
S X SY	NS		NS	*	NS
Nutsedge planting time (PT; WAT)					
0	0.54	7.38	29.31	52.2	64.0
1	---	2.80	15.35	37.6	55.1
3	---	---	1.89	13.5	41.4
5	---	---	---	1.3	19.0
7	---	---	---	---	11.0
S X PT	---		***	**	**
SY X PT	---		***	*	NS
S X SY X PT	---	***	NS	NS	NS

[z]End-of-season nutsedge dry weights were obtained from plants sampled 15 and 14 WAT in spring and fall, respectively.

[NS, *, **, ***]Main effects were nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively, according to F tests.

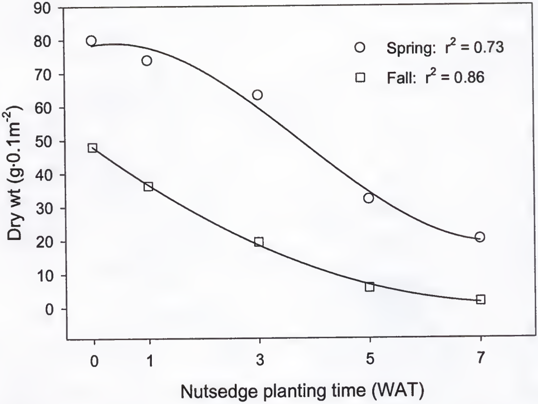


Fig. 2-6. Interaction of season (2000) and yellow nutsedge planting time on end-of season nutsedge shoot dry weight. Data within means (shown) were regressed with a cubic or quadratic model in spring and fall, respectively. Equations were $Y = 78.3 + 3.19(X) - 4.26(X^2) + 0.372(X^3)$ and $Y = 48.0 - 12.2(X) + 0.792(X^2)$ for spring (○) and fall (□), respectively.

CHAPTER 3
DISTANCE BETWEEN YELLOW NUTSEDGE AND BELL PEPPER AT WHICH PEPPER GROWTH AND YIELD IS REDUCED

Introduction

Weeds compete with crops for resources such as light and nutrients. Competition is a function of distance between crop and weed plants. Torner and Gonzales-Andujar (1993) found that the presence of one black nightshade (*Solanum nigrum* L.) plant 10, 80, and 110 cm from a pepper plant reduced yield by 59%, 26%, and 9%, respectively. Similarly, Perry and Currey (1985) reported 14% less soybean plant dry weight with sicklepod (*Cassia obtusifolia* L.) grown 25 than 50 cm from soybean plants.

The distance between bell pepper and yellow nutsedge plants at which pepper yield is reduced has not been defined. This information is needed to design strategies for managing nutsedge infestations without the use of methyl bromide. This study, therefore, was conducted to determine the effect on pepper yield of yellow nutsedge tubers planted at varying distances from pepper.

Materials and Methods

Design

Experiments were conducted during spring and fall on a Kanapaha fine sand (loamy siliceous, hyperthermic, Grossarenic Paleaquult) in 1999 and on an Arredondo fine sand (loamy, siliceous, hyperthermic, Grossarenic Paleudult) in 2000 at the Horticultural Research Unit of the University of Florida in Gainesville, Fla. Treatments

were arranged as a 2 X 5 factorial replicated five times with two spacings (5 and 10 cm) of yellow nutsedge tubers planted in five circle radii from a pepper plant of 0 (no nutsedge), 7.6, 15.2, 22.9, or 30.5 cm (30.5 cm is the maximum available circle size on the 61 cm bed tops). A circle with a radius of 7.6, 15.2, 22.9, or 30.5 cm received 9, 19, 28, or 38 tubers, respectively, with tubers spaced 5 cm apart. With tubers spaced 10 cm apart, a circle with the same radii received 4, 9, 14, or 19 tubers, respectively.

<u>Establishment and Maintenance Procedures</u>

Beds were formed on 1.2 m centers, fumigated with 392 $kg \cdot ha^{-1}$ of 75:25 methyl bromide:chloropicrin injected 20 cm deep with two shanks, and covered with polyethylene mulch (Sonoco; 0.0038 cm thickness; black in spring; white in fall). Planting holes for pepper were punched in single rows per plot at an in-row spacing of 46 cm. Holes for nutsedge tubers were punched via a board with dowels 7.6 cm long spaced 5 cm apart to form the four circles. Nutsedge planting holes were punched around every other pepper planting hole (six per 6.4 m long plot). Holes were punched one to two weeks after fumigation, but in fall 1999 they were punched five weeks after fumigation (Table 3-1).

Bell pepper ('X3R Camelot') seedling and nutsedge tuber planting began on the day holes were punched (Table 3-1). For the 5 cm tuber spacing each nutsedge planting hole, or for the 10 cm tuber spacing every other hole, received one nutsedge tuber ['Chufa' tubers, a cultivated variety (*sativus*) of native yellow nutsedge (de Vries, 1991), were used]. Nutsedge seedlings from planted tubers were allowed to proliferate throughout the season.

Drip irrigation with biwall tubing (orifice diameter, 0.025 cm; emitter spacing, 30 cm; flow rate of 1.89 L per 30.5 m per min) placed on the soil surface at the middle of each bed was used to supply water as needed to prevent moisture stress to plants. Irrigation times for each week were scheduled to apply approximately 75% of the mean daily volume of ET for the previous seven days.

During each season, plants received 224 N:37 P:186 K $kg \cdot ha^{-1}$. All P and 40% of N and K were preplant-incorporated during bed formation. The remainder of N and K was fertigated in 10 equal weekly applications each season. Pesticides were applied as needed to control insects and diseases.

Measured and Derived Variables

During each season, measured variables included pepper and nutsedge plant height, pepper leaf area and number, dry weight of pepper (leaf and stem) and nutsedge (shoots) plants, nutsedge shoot number, N concentration in pepper fruit and in pepper and nutsedge plants, and harvested pepper fruit weight. Pepper leaf and stem dry weights were summed to obtain total dry weight per pepper plant. Dry weight data from pepper plants grown weed-free were used to calculate percent losses of leaf, stem, and total dry weight.

Concentrations of N in pepper plants were determined for harvested fruit, leaf, and stem tissue, and N uptakes were calculated. Harvested fruit N uptake was calculated by multiplying fruit N concentration by fruit dry weight (calculated via a sample of harvested fruit). Fruit N uptake for each harvest during each season was summed to obtain total fruit N uptake. Accumulation of N by pepper leaf, stem, and fruit tissue was the product of N concentration multiplied by dry weight.

Nutsedge dry weight and N concentration data were collected for shoot tissue. Uptake of N by nutsedge shoots was derived from nutsedge shoot dry weight and N concentration. Nutsedge shoot N uptake was derived from the dry weight of a known number of shoots (1999) or all the shoots (2000) in a 25-cm long segment of a nutsedge circle. The nutsedge sampling method in 1999 was changed in 2000 to maximize the likelihood of obtaining a representative sample. Nutsedge shoot number per circle was derived from the number of shoots in a 25-cm long segment of a circle.

Harvested pepper fruit weight data for each harvest were summed to obtain total fruit weight for each fruit size category. Large fruit yield was derived from the sum of U.S. Fancy and U.S. No. 1 fruit. Yields of U.S. Fancy, U.S. No. 1 and U.S. No. 2 fruit were summed to obtain marketable fruit yield. Total yield was the sum of yield for all fruit grades including culls. Harvested fruit yields were converted to percent loss, relative to values obtained with pepper grown weed-free.

Data Collection Procedures

Pepper plant heights and nutsedge heights and shoot numbers were obtained during pepper flowering, fruit development, and at or after final fruit harvest (Table 3-1). Heights (distance between the bed surface and the highest bud) of the same two pepper plants per plot, both of which were surrounded by nutsedge plants were measured each time.

Heights of four nutsedge leaf blades in each of the two circles surrounding the above-mentioned pepper plants were obtained by measuring the distance from the bed surface to the highest growing point. Nutsedge shoot numbers were obtained within a representative 25-cm segment of one nutsedge circle in each plot; this segment was

marked with two wooden stakes placed 25 cm apart so that shoots in the same area were counted each time. Nutsedge shoot heights and numbers were obtained on the same day (Table 3-1).

Pepper fruits were harvested twice each season except for fall 1999 when peppers were harvested once due to an insufficient quantity of fruit for a second harvest (Table 3-1). Weights were recorded for U.S. Fancy, U.S. No.1, and U.S. No. 2 fruit according to U.S. Dept. of Agriculture standards. A sample, usually four fruits, was collected from the fruit harvested in each plot. These fruits were dried at 60 °C, weighed, and ground to a particle size of < 0.6 mm diameter. Total kjeldahl N (TKN) was determined using 100 mg samples digested in H_2SO_4 and analyzed by Rapid Flow Colorimetry (Hanlon et al., 1996).

Two representative pepper plants per plot were sampled to obtain growth parameter data shortly after fruit harvest (Table 3-1). Leaves were separated from the stem of each plant. Leaves on each plant were counted and passed through an area meter (LI-3100; LI-COR; Lincoln, NE) to obtain total leaf-plus-petiole area per pepper plant. Total N concentration was determined for leaf and stem tissue via TKN analysis.

Data Analysis Procedures

Data were subjected to analysis of variance using SAS (SAS, 2000). Yield loss responses to tuber circle radius were characterized via orthogonal polynomials or a best-fit nonlinear equation, and respective coefficients of determination (r^2) were determined with regression analysis. Data pertaining to pepper leaf number, leaf dry weight, leaf area, stem dry weight, and total dry weight were analyzed as actual values. Polynomial

contrasts were used to describe pepper and nutsedge growth parameter responses to tuber circle radius.

Results and Discussion

Pepper Fruit Yield

Year and season effects on pepper fruit yields were contained in interactions of year, season, and tuber circle radius (Table 3-2). Large, marketable, and total fruit weights were greater while weight losses (%) were lower with tubers spaced 10 than 5 cm apart within circles. These results were expected as more tubers were planted per circle when spaced 5 than 10 cm apart.

Year interacted with season and tuber circle radius on percent loss of fruit weights (Table 3-2; Fig 3-1) due to differences in temperature and rainfall between seasons (Table 3-3) as discussed below. During spring 1999, large and marketable fruit yield reductions were less with tubers planted in a circle 7.6 than 15.2 to 30.5 cm from pepper. In contrast, during fall 1999, large and marketable yield reductions were less with tubers planted 30.5 than 7.6 to 22.9 cm from pepper.

During spring and fall 1999 seasons, large and marketable pepper fruit weight reductions declined slightly with an increase in tuber circle radius from 22.9 to 30.5 cm (Fig. 3-1). Although coefficients of determination (r^2) in fall 1999 were low, combined spring and fall 1999 data suggested that nutsedge interference with pepper declined with an increase in tuber circle radius from 22.9 to 30.5 cm. Even at the maximum distance of 30.5 cm of planted tubers from pepper, however, nutsedge interference reduced pepper yield by over 60%.

Large and marketable fruit weight losses during spring and fall 2000 were not differentially influenced by nutsedge circle radius (Fig. 3-1). During these seasons, nutsedge interference reduced pepper yields by over 58% with all tuber circle radii.

Response of total pepper fruit weight loss (%) to nutsedge circle radius was similar to that observed for large and marketable fruit in all seasons except spring 2000 (Fig 3-1). Total fruit weight loss response to tuber circle radius in spring 2000, though poorly correlated to circle radius, resembled that in spring 1999. During both spring seasons, total yield losses were maximized with tubers planted 22.9 cm from pepper; however, maximum yield losses were lower in spring 2000 than spring 1999.

Total fruit weight losses during fall 2000 were similar with all tuber circle radii used (Fig. 3-1). Nutsedge interference reduced total fruit weight in fall 2000 by at least 75% with all circle sizes.

High pepper fruit yield losses with nutsedge plants at all radii from pepper were due to tuber and subsequent plant densities resulting from planted in-circle tuber spacings. All resulting tuber densities (65 tubers$\cdot$m^{-2} with tubers planted 10 cm apart and 30.5 cm from pepper to 500 tubers$\cdot$m^{-2} with tubers spaced 5 cm apart and 7.6 cm from pepper) were greater than 30 to 45 tubers$\cdot$m^{-2} that, after germination and season-long growth, resulted in the biological threshold (Fig. 1-1). A nutsedge tuber density of 65 tubers$\cdot$m^{-2} in a field is not unrealistic. On May 11 in a spring season, Locascio and Dickson (2000) observed 181 nutsedge (mixture of yellow and purple) plants per square meter in non-fumigated field plots. Because 65 tubers$\cdot$m^{-2} planted at 30.5 cm from a pepper plant resulted in > 65% pepper fruit yield losses, yellow nutsedge would have to be controlled to the edge of planting beds.

Pepper Height

Pepper plant heights during pepper fruit development and after final fruit harvest were similar in 1999 and 2000 (Table 3-4); however, year and season interacted in their effects on pepper plant height during flowering (Table 3-5) primarily because plants in fall 2000 were shorter than those in fall 1999 and spring 2000. By the 3rd WAT, plants grown in fall 2000 received 20 cm of rainfall water compared to 10 and 7 cm received by plants grown in fall 1999 and spring 2000, respectively (Table 3-3). High early-season rainfall in fall 2000 may have slowed the growth of pepper plants. During pepper fruit development and after final fruit harvest, pepper plants were taller in spring than fall seasons (Table 3-4).

Tuber spacing had no influence on pepper heights, but tuber circle radius influenced pepper plant height (Table 3-4). At pepper flowering , fruit development, and fruit harvest (final) stages, mean nutsedge interference with all tuber circle sizes increased pepper plant heights compared to heights with no nutsedge.

At flowering, pepper plant heights declined linearly with increasing nutsedge circle radius. After pepper flowering, pepper plant heights were similar with nutsedge tuber circle radii from 7.6 to 30.5 cm.

Growth Parameters of Pepper Plants Sampled After Fruit Harvest

With the exception of leaf number, values for growth parameters of pepper plants sampled after fruit harvest were greater in 1999 than 2000 (Table 3-6). The season effect was influenced by radius as discussed below. Tuber spacing within circles had no influence on end-of-season pepper leaf number, leaf area, and biomass.

Tuber circle radius (7.6 to 30.5 cm) effects on all growth parameters varied with season (Tables 3-6 and 3-7). During spring and fall seasons, values for all growth parameters were over 40% greater with pepper grown weed-free than with pepper subjected to nutsedge interference (Table 3-7). Therefore, yellow nutsedge greatly reduced not only pepper fruit yield, but also pepper plant size.

In spring seasons, values for all growth parameters appeared highest when tubers were planted 7.6 cm from pepper and were similar with an increase in tuber circle radius from 15.2 to 30.5 cm (Table 3-7). In fall seasons, leaf number, leaf dry weight, and leaf area increased linearly or quadratically with an increase in tuber circle radius from 7.6 to 30.5 cm. Pepper stem and total (leaf + stem) dry weights were not differentially influenced by nutsedge circle size.

Pepper Plant N Concentration

Concentration of N (TKN) was determined for harvested pepper fruit and leaf and stem tissue of pepper plants sampled after fruit harvest as shown in Table 3-8. Year effects on N concentrations were contained in interactions explained below. Year and season interacted on leaf and stem N concentration primarily because of season effects within years (Table 3-9). Leaf and stem N concentrations in 1999 were greater in fall than spring. In 2000, on the other hand, leaf and stem N concentrations were similar during spring and fall.

Nutsedge tuber spacing had no effect on pepper leaf N conc, but season interacted with tuber spacing on stem N concentration (Tables 3-8 and 3-10). This interaction occurred because stem N concentration with tubers spaced 5 cm apart within circles was less in fall than spring seasons (Table 3-10).

Nutsedge tuber circle radius interacted with year, season, and tuber spacing on pepper fruit N concentration (Tables 3-8 and 3-11). Nitrogen concentrations below 2%, as shown in Table 3-11, were due to 'zero' values used for plots with no fruit. This occurred in fall seasons during which fruit yields were low (Table 3-2).

Fruit N concentrations, except for those in fall 2000 with tubers spaced 5 cm apart, were not influenced by nutsedge interference with tubers planted 7.6 to 30.5 cm from pepper (Table 3-11). In fall 2000, with tubers spaced 5 cm within circles, fruit N concentration was greater with pepper grown without than with nutsedge interference. Therefore, nutsedge interference reduced pepper fruit N concentration by reducing fruit development.

In 1999, spring-season pepper fruit N concentration, with tubers spaced 5 cm apart, did not change as tuber circle radius was increased from 7.6 to 30.5 cm (Table 3-11). With tubers spaced 10 cm apart, spring-season pepper fruit N concentrations in 1999 increased linearly with an increase in tuber circle radius from 7.6 to 30.5 cm. In fall 1999, with tubers spaced 5 cm apart, the quadratic fruit N concentration response to tuber circle radius was due to the absence of fruit in some plots. With tubers spaced 10 cm apart, in fall 1999, all plots had pepper plants with fruit, and nutsedge N concentrations were not influenced by tuber circle radius. In spring and fall of 2000, fruit N concentrations did not change appreciably with tuber circle radius regardless of tuber spacing within circles. Only in spring 1999, therefore, with tuber spaced 10 cm apart within circles, did pepper fruit N concentration increase with an increase in tuber circle radius from 7.6 to 30.5 cm.

Pepper leaf N concentration with pepper grown weed-free was similar to that with nutsedge interference, and leaf N concentration was not influenced by initial nutsedge tuber circle size (Table 3-8). Nutsedge interference reduced pepper stem N concentration by 17% compared to N concentration in stems of pepper plants grown weed-free, but stem N concentrations did not vary over tuber circle radii.

Lorenz and Hochmuth (1988) reported a N sufficiency range for bell pepper of 1.5% to 2.5% dry weight of leaf tissue sampled at full bloom with fruits 75% of full size. Leaf N concentrations in the present study exceeded 2.5% with plants sampled at the end of the season. Because pepper plant N concentration declined with time in the tuber population experiment (Table 1-35), leaf N concentrations during pepper fruit development would likely have been greater than those at the end of the season (Table 3-8), and, thus, greater than 2.5%. Because leaf dry weight was 56% greater than stem dry weight, it is doubtful that nutsedge competed significantly with pepper for N.

Pepper N Uptake

Accumulation of N by harvested pepper fruit, leaf and stem tissue from plants sampled after fruit harvest, and total (fruit + leaf + stem) N uptake values are shown in Table 3-8. Leaf and total N uptakes were greater in 1999 than 2000. Year interacted with season on fruit and stem N uptake. Year interacted with season on fruit N uptake because, in spring, N uptake was greater in 2000 than 1999 while in fall it was similar in 1999 as in 2000 (Table 3-12). Year interacted with season on stem N uptake because the decline in stem N accumulation from 1999 to 2000 was greater in spring than fall. This was likely due to high rainfall early in the fall 2000 season (Table 3-3) which slowed pepper plant growth.

Tuber spacing within circles influenced pepper fruit and total N accumulation but not leaf and stem N uptake (Table 3-8). Pepper fruit and total N accumulations were greater with tubers planted 10 than 5 cm apart.

Season and tuber circle radius interacted in their effects on fruit, leaf, stem, total N uptakes (Tables 3-8 and 3-13). Fruit, leaf, stem, and total N uptakes in spring and fall seasons were over 50% greater without than with nutsedge (Table 3-13). Fruit, leaf, stem, and total N accumulations in spring seasons decreased quadratically with an increase in tuber circle radius from a pepper plant of 7.6 to 30.5 cm. Fruit and total N uptakes appeared lowest with tubers planted 22.9 cm from pepper. Therefore the effects of tuber circle radius on pepper plant N uptake (Table 3-13) were consistent with those on pepper fruit production (Fig. 3-1) and end-of-season vegetative growth parameters (Table 3-7), and results showed that spring-grown pepper plants were more competitive with nutsedge grown 7.6 than 15.2 to 30.5 cm from pepper plants. Results for spring-grown pepper, therefore, contrasted with reports of greater interference of weeds grown close than further away from a crop plant (Perry and Currey, 1985; Torner and Gonzales-Andujar, 1993). These contrasting results may be explained by yellow nutsedge growth habit.

In the present study, it was observed that nutsedge leaf blades laid over and fell across the top of pepper plants as they lengthened. The extent of nutsedge leaf coverage of pepper, however, depended on the proximity (circle size) of nutsedge plants to a pepper plant. When grown in a circle close to a pepper plant, nutsedge grew in clump fashion with most leaves falling away from the pepper leaf canopy. With increased distance between nutsedge and a pepper plant, nutsedge leaf coverage of pepper

increased. Therefore, light availability to pepper plants appeared greater with nutsedge grown close than further away from pepper. This may explain greater pepper plant competitiveness in spring 1999 with nutsedge plants 7.6 than 15.2 to 30.5 cm from pepper.

In fall seasons, fruit and total N uptake were lowest and similar with tubers planted 7.6 to 22.9 cm from pepper (Table 3-13). Fruit and total N uptake in fall seasons appeared to increase with an increase in tuber circle radius from 22.9 to 30.5 cm. Leaf and stem N accumulations in fall seasons were not differentially influenced by tuber circle radii. The observation that pepper plant and fruit N uptakes in fall seasons were lowest with nutsedge tuber circle radii of 7.6 to 22.9 or not differentially influenced by circle size was consistent with that of pepper fruit production (Fig. 3-1) and plant growth parameters (Table 3-7). Therefore, the effects of tuber circle radii on pepper plant growth and fruit production in spring contrasted with those in fall seasons. This was likely due to higher early-season temperatures in fall than spring seasons (Table 3-3) as discussed below.

Nutsedge Shoot Height

Year and season effects on nutsedge shoot heights were contained in interactions (Table 3-14) described below. Year interacted with season on nutsedge shoot height after pepper fruit harvest (Table 3-15) because shoots were 11 cm taller in fall 2000 than fall 1999.

Tuber spacing within circles did not affect nutsedge shoot heights at pepper flowering (Table 3-14). At the end of the season, in-circle tuber spacing effects on nutsedge heights varied with year (Table 3-16). In 1999, nutsedge shoot heights were

similar with tubers spaced 5 and 10 cm apart, but shoots in 2000 were taller with tubers planted 10 than 5 cm apart (Table 3-16). There was not a strong tuber spacing effect within years on shoot height. With tubers spaced 5 and 10 cm, shoot heights were greater in 2000 than 1999.

In-circle tuber spacing also interacted with season on end-of-season nutsedge shoot height (Tables 3-14 and 3-17). In spring seasons, shoots were 4 cm taller with tubers spaced 10 than 5 cm apart (Table 3-17). In fall seasons, shoot heights were similar between tuber spacings. Within seasons, then, tuber spacing within circle effects were weak. The season effect within each tuber spacing, though, was strong. Nutsedge shoots, with tubers spaced 5 or 10 cm apart, were taller in spring than fall seasons.

Year, season, nutsedge tuber spacing within circles, and tuber circle radius interacted in their effects on nutsedge shoot height during pepper flowering (Tables 3-14 and 3-18). In spring 1999, with tubers spaced 5 cm apart, nutsedge shoot height decreased linearly with an increase in tuber circle radius from 7.6 to 30.5 cm. With tubers spaced 10 cm apart, nutsedge shoot heights in spring 1999 were similar with all tuber circle radii used. In fall 1999, with tubers spaced 5 cm apart, nutsedge shoot height declined linearly with increased tuber circle radius. With tubers spaced 10 cm, in fall 1999, nutsedge height increased with an increased in tuber circle radius from 7.6 to 22.9 cm and then decreased with an increase in tuber circle radius from 22.9 to 30.5 cm. Therefore, nutsedge shoot shoots in 1999 were usually shorter with tubers planted 30.5 than 7.6 to 22.9 cm from pepper. These data were consistent with a slight decline in spring-season fruit yield loss (%) as tuber circle radius was increased from 22.9 to 30.5 cm (Fig. 3-1).

In spring 2000 during pepper flowering, with both tuber spacings, shoot heights changed little with increased tuber circle radius (Table 3-18). Shoots, from tubers planted 22.9 and 30.5 cm from pepper, were 10 cm shorter in spring 2000 than spring 1999, possibly due to cooler early-season temperatures in spring 2000 than spring 1999 (Table 3-3). This was consistent with the observation that maximum total pepper fruit yield loss to nutsedge interference was greater in 1999 than 2000 (Fig 3-1).

In fall 2000, nutsedge shoot height increased linearly with increases in tuber circle radius with tubers spaced 5 cm in circles (Table 3-18), possibly due to less lodging of nutsedge shoots in fall 2000 than fall 1999. With tubers spaced 10 cm within circles in fall 2000, nutsedge shoot height did not change with increases in tuber circle radius.

Height of nutsedge vs. pepper at pepper flowering was important because, as discussed in Chapter 2, substantial reductions in bell pepper plant growth and yield were predicted with 6 weeks of nutsedge interference. During pepper flowering, in the present study, nutsedge shoots appeared taller in fall than spring seasons; and nutsedge shoot heights at the pepper flowering stage (Table 3-18) exceeded that of pepper plant heights (Table 3-4) to a much greater extent in fall than spring seasons (Tables 3-4 and 3-18). This was most likely a result of higher early-season temperatures in fall than spring seasons (Table 3-3).

High early-season nutsedge growth and vigor in fall accounted for greater pepper fruit yield losses (Table 3-2) and less end-of-season pepper vegetative biomass (Table 3-7) and N accumulation (Table 3-13) in fall than spring seasons. It may also explain contrasting spring- and fall-season effects of an increase in tuber circle radius from 7.6 to 30.5 cm on bell pepper plant growth (Table 3-7) and fruit production (Fig. 3-1).

Although nutsedge growth habit was the same in spring and fall seasons, leaf blades arising from nutsedge tubers planted at all distances from pepper appeared to cover pepper plants more completely in fall than spring seasons at 6 WAT. These observations indicate that nutsedge competed with pepper for light.

Pepper plants were also sensitive to shading by nutsedge in the tuber population experiment (Chapter 1), and this was consistent with a report by Pike et al. (1990) where soybean yield losses were highly correlated to the leaf area of weeds *(Datura stramonium* L. and *Xanthium strumarium* L. *)* directly above the weed-crop canopy.

During the pepper fruit development stage, nutsedge shoot height was influenced by the interacting effects of year, season and nutsedge tuber circle radius (Tables 3-14 and 3-19). Overall, nutsedge shoot heights in each of the four seasons changed little with increases in tuber circle radius, but heights appeared taller in spring than fall seasons (Table 3-19).

At the end of the season, nutsedge shoot heights declined quadratically with an increase in initial tuber circle radius from 7.6 to 30.5 cm (Table 3-14). Shoot heights were somewhat shorter with tubers planted 30.5 than 7.6 to 22.9 cm from pepper, possibly because shoots from tubers planted 30.5 cm from pepper were more susceptible to lodging than shoots from tubers planted closer to pepper.

<u>Nutsedge Shoot Number</u>

Nutsedge shoot numbers were expressed on a per circle basis. This was done by multiplying the number of shoots present in a 25-cm long segment of a circle by the number of 25-cm segments within the circumference of the circle. Shoots were not

counted during pepper flowering in spring 1999. Consequently, the data for shoot number during pepper flowering were presented in Table 3-14 but not analyzed.

Year and season interacted on nutsedge shoot number at pepper fruit development (Tables 3-14 and 3-15) where, in both years, spring-planted tubers had produced more shoots than those planted in fall seasons (Table 3-15). By the time pepper fruits were developing, nutsedge shoot proliferation in the fall seasons had declined due to a decrease in daylength over time. Tubers planted in fall 2000, however, produced more shoots than those planted in fall 1999, apparently a response to an earlier planting date in fall 2000 than fall 1999 (Table 3-1). Shoot numbers in spring 1999 and spring 2000 were similar (Table 3-15).

Nutsedge shoots were more numerous during pepper fruit development with tubers planted 5 than 10 cm apart within circles (Table 3-14). By the end of the season, however, initial nutsedge tuber spacing no longer influenced nutsedge shoot numbers.

Tuber circle radius effects on nutsedge shoot number during pepper fruit development varied with year (Tables 3-14 and 3-20). In 1999, nutsedge shoot number increased in cubic fashion with an increase in tuber circle radius from 7.6 to 30.5 cm because shoot number decreased slightly as tuber circle radii were increased from 15.2 to 22.9 cm (Table 3-20). It was unclear why this occurred. In 2000, shoot number per circle increased linearly from 284 to 836 shoots per circle with an increase in tuber circle radius from 7.6 to 30.5 cm.

Tuber circle radius effects also interacted with those of season (Table 3-14 and 3-21) on nutsedge shoot number during pepper fruit development. In spring seasons, shoot numbers increased in a cubic fashion with an increase in tuber circle radius from 7.6 to

30.5 cm. In fall seasons, nutsedge shoot number increased linearly with an increase in tuber circle radius from 7.6 to 30.5 cm. Generally, therefore, shoot number per circle increased with increased circle size. This was as expected because more tubers were planted in larger than smaller circles.

Year, season, and initial tuber circle radius interacted in their effects on shoot number after final pepper fruit harvest (Tables 3-14 and 3-19). In spring seasons, shoots were more numerous in 1999 than 2000, and shoot numbers increased more sharply with increases in tuber circle radius in spring 1999 than spring 2000 (Table 3-19). Shoot numbers in spring seasons appeared greater than those in fall seasons, and shoots were more numerous and increased more sharply with increases in tuber circle radius in fall 2000 than in fall 1999.

Nutsedge shoot height and number data (Tables 3-14, 3-15, 3-18, and 3-19) showed that nutsedge growth and vigor increased over time in spring seasons and declined over time in fall seasons. The apparent sensitivity of yellow nutsedge to daylength was in agreement with reports that vegetative growth of yellow nutsedge increases with an increase in photoperiod (Jansen, 1971; Williams, 1982).

Taller and more numerous nutsedge plants during the pepper fruit development stage in spring than fall seasons (Tables 3-14 and 3-19) indicated that nutsedge growth and vigor had declined between the 6th and 9th WAT in fall seasons. This decline in fall-season nutsedge growth did not, however, occur soon enough to prevent substantial pepper fruit yield losses.

Nutsedge Shoot Dry Weight

Tuber spacing had no effect on the dry weight of nutsedge shoots at the end of the season. Year, season, and tuber circle radius interacted in their effects on dry weight of nutsedge shoots sampled after final pepper fruit harvest (Tables 3-13 and 3-19). Nutsedge dry weight increased with an increase in tuber circle radius in each season except in fall 1999 where circle radii had no effect (Table 3-19). The major source of the interaction was that the increase in dry weight with an increase in tuber circle radius was greater in spring 1999 than in the other seasons. Nutsedge shoot biomass during 1999 and 2000 appeared much greater in spring than fall seasons. This was consistent with nutsedge shoot height and shoot number data (Table 3-19) and provided further evidence that yellow nutsedge was sensitive to photoperiod as reported by Janson (1971) and Williams (1982).

Nutsedge N Concentration and Uptake

Nutsedge shoots sampled at the end of the season contained more N in 1999 than 2000 and in spring than fall (Table 3-22). Year and season effects on N uptake by nutsedge were contained in an interaction with nutsedge circle radius as discussed below. Nutsedge tuber spacing within circles had no influence on end-of-season nutsedge shoot N concentration and uptake.

Nutsedge tuber circle radius did not affect nutsedge shoot N concentration, but year, season, and radius interacted in their effects on nutsedge shoot N uptake (Tables 3-22 and 3-19). Accumulation of N by nutsedge shoots increased with an increase in tuber circle radius in all seasons except fall 1999 when N uptake was not influenced by tuber circle size (Table 3-19). As with nutsedge shoot number (Table 3-19), the main

source of the interaction was that shoots accumulated more N in spring 1999 than in the other seasons.

Nutsedge shoot N concentrations (Table 3-22) were low and similar to those at the end of each season in the nutsedge tuber population experiment (Tables 1-53, 1-54, and 1-55). Accumulations of N by nutsedge in both studies (Tables 1-53, 1-54, 1-55, and 3-22), however, were greater than N taken up by pepper plants sampled at the end of each season (Tables 1-45, 1-46, 1-47, and 3-13). Therefore, yellow nutsedge appeared to use N more efficiently than bell pepper even though N was not limiting for pepper growth.

Table 3-1. Dates during each season in 1999 and 2000 for planting and events at late pepper flowering, during fruit development, at fruit harvest, and at or after final fruit harvest.

	1999		2000	
	Spring	Fall	Spring	Fall
Planted pepper	24 March	2 Sept.	23 March	16 Aug.
Planted nutsedge	24-25 March	30 Aug.	22 March	16-17 Aug.
	During pepper flowering			
Plant ht measured[z]	3 May	12 Oct.	4 May	26 Sept.
Nutsedge shoots counted	data not obtained	12 Oct.	4 May	26 Sept.
	During pepper fruit development			
Plant ht measured[z]	2 June	1 Nov.	30 May	18 Oct.
Nutsedge shoots counted	2 June	2 Nov.	30 May	17 Oct.
	At first and second pepper fruit harvest			
1st: Fruit no. and wt. recorded	16 June	22 Nov.	9 June	6 Nov.
2nd: Fruit no. and wt. recorded	25 June	---	25 June	15 Nov.
	Nearly at or after final pepper fruit harvest			
Plant ht measured[z]	24 June	23 Nov.	28 June	15 Nov.
Nutsedge shoots counted and sampled	24 June	24 Nov.	28-29 June	20 Nov.
Pepper plants sampled	30 June	29 Nov.	26-27 June	15 Nov.

[z]Pepper plant and nutsedge shoot heights were obtained.

Table 3-2. Main effects of year, season, initial nutsedge yelow nutsedge tuber spacing within circles, and tuber circle radius on large, marketable, and total bell pepper fruit weight.

	Pepper fruit yield ($t \cdot ha^{-1}$ and % loss)					
	Large		Marketable		Total	
Treatment	$t \cdot ha^{-1}$	% loss[Z]	$t \cdot ha^{-1}$	% loss	$t \cdot ha^{-1}$	% loss
Year (Y)						
1999	4.71	74.2	5.37	71.8	6.37	76.3
2000	4.13	72.1	6.14	74.1	7.49	75.3
Season (S)						
Spring	6.25	63.0	8.06	63.7	9.95	68.9
Fall	2.41	84.6	3.16	83.1	3.51	83.5
Tuber spacing (TS; cm)						
5	4.07	79.1	5.23	78.1	6.31	80.8
10	4.79	67.4	6.24	67.6	7.48	70.9
Signif.	*	***	**	***	**	***
Radius (RAD; cm)						
0	10.02	-	13.35	-	16.91	-
7.6	4.38	62.5	5.28	63.4	6.32	67.2
15.2	2.51	78.7	3.32	77.2	3.76	80.0
22.9	2.19	80.9	2.71	81.2	3.14	82.6
30.5	3.07	70.8	4.01	69.7	4.37	73.5
Y X S X RAD	***	***	***	***	**	***

[Z]Values were expressed as percent loss relative to those obtained with pepper grown weed-free (0 RAD).

NS, *, **, ***Main effects and interactions were nonsignificant or significant at $P \leq 0.05$, 0.01, 0.001, respectively, according to F tests.

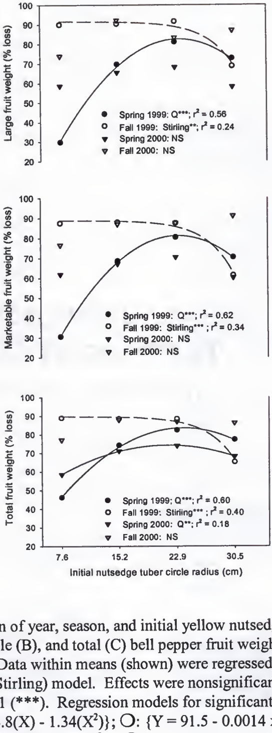


Fig. 3-1. Interaction of year, season, and initial yellow nutsedge tuber circle radius on large (A), marketable (B), and total (C) bell pepper fruit weight loss relative to yield with no nutsedge. Data within means (shown) were regressed with a quadratic (Q) or best-fit nonlinear (Stirling) model. Effects were nonsignificant (NS) or significant at P ≤ 0.01 (**) or 0.001 (***). Regression models for significant radius effects were: A.) ●: $\{Y = -32.0 + 24.8(X) - 1.34(X^2)\}$; ○: $\{Y = 91.5 - 0.0014 \times e^{(0.273(X))} - 1/0.273\}$. B.) ●: $\{Y = -30.5 + 24.4(X) - 1.34(X^2)\}$; ○: {Y = 88.8 - 0.0015 x e(0.279(X) -1/0.279} C.) ●: $\{Y = 3.26 + 17.2(X) - 0.921(X^2)\}$; ○: $\{Y = 89.6 - 0.0016 \times e^{(0.273(X))} - 1/0.273\}$; ▼ = $\{Y = 37.2 + 8.67(X) - 0.508(X^2)\}$.

Table 3-3. Daily minimum and maximum temperature and rainfall averaged within time periods corresponding to physiological pepper growth stages during each season.

Time (days)	Avg.temp. (°C) Min	Max	Rainfall (cm)	Time (days)	Avg. temp. (°C) Min	Max	Rainfall (cm)
	Spring 1999				Fall 1999		
1-21	13	31	0.0	1-21	19	32	10.4
22-40[z]	12	27	1.6	22-40[z]	20	30	11.5
41-70[y]	17	31	10.1	41-60[y]	13	27	1.7
71-93[x]	20	31	11.0	61-81[x]	9	25	3.6
Total			22.8	Total			27.3
	Spring 2000				Fall 2000		
1-21	10	25	6.8	1-21	21	31	19.8
22-40[z]	11	26	1.8	22-41[z]	21	29	13.2
43-68[y]	18	32	1.8	42-63[y]	14	26	1.6
69-94[x]	19	32	21.8	64-91[x]	13	26	0.4
Total			32.3	Total			34.9

[z]First plant height measurement during the four seasons at late pepper flowering/early fruit set was on day 40, 40, 40, and 41 of seasons, respectively.

[y]Second plant height measurement during the four seasons at pepper fruit development was on day 70, 60, 68, and 63 of seasons, respectively.

[x]Final pepper fruit harvest during the four seasons was on day 93, 81, 94, and 91 of seasons, respectively.

Table 3-4. Main effects of year, season, yellow nutsedge tuber spacing within circles, and tuber circle radius on bell pepper plant height at pepper flowering, fruit development, and after fruit harvest.

	Pepper ht at three growth stages (cm)		
Treatment	Flowering	Fruit development	Fruit harvest
Year (Y)			
1999	27.2	43.6	46.7
2000	26.6	40.6	46.5
Signif.	NS	NS	NS
Season (S)			
Spring	26.2	50.7	58.3
Fall	27.7	32.7	33.6
Signif.	NS	***	***
Y X S		NS	NS
Tuber spacing (cm)			
5	28.1	44.4	49.4
10	27.1	43.4	47.4
Signif.	NS	NS	NS
Radius (RAD; cm)			
0	24.2	35.3	39.1
7.6	28.7	44.8	48.3
15.2	28.5	45.0	50.8
22.9	26.9	43.5	47.9
30.5	26.1	42.3	46.7
0 vs. nutsedge	***	***	***
Nutsedge (7.6 to 30.5 cm)	L**	NS	NS

NS, **, ***Main effects and interactions were nonsignificant or significant at $P \leq 0.01$, 0.001, respectively, according to F-tests. Competition (7.6 to 30.5 cm RAD) vs. no competition (0 RAD) effects were tested with contrasts. Significant radius effects were linear (L) according to polynomial contrasts.

Table 3-5. Interaction of year and season on bell pepper plant height at pepper flowering.

	Season		
Year	Spring	Fall	Signif.
1999	23.2	31.2	***
2000	29.2	23.3	*
Signif.	***	*	

*,*** Column and row effects were significant at $P \leq 0.05$ or 0.001, respectively, according to F tests.

Table 3-6. Main effects of year, season, yellow nutsedge tuber spacing within circles, and tuber circle radius on bell pepper plant leaf number, leaf dry weight, leaf area, stem dry weight, and total (leaf + stem) dry weight measured after pepper fruit harvest.

	Pepper growth parameter (no., g, or $cm^2 \cdot plant^{-1}$)				
Treatment	Leaf (no.)	Leaf wt (g dry wt)	Leaf area (cm^2)	Stem wt (g dry wt)	Total wt (g dry wt)
Year					
1999	61.3	9.6	1590	14.5	24.1
2000	58.9	6.6	1314	13.7	20.7
Signif.	NS	***	***	***	***
Season (S)					
Spring	82.7	10.7	2037	21.1	31.9
Fall	35.1	5.4	817	5.5	11.1
Tuber spacing (cm)					
5	44.0	5.6	1024	10.7	16.4
10	46.9	6.1	1127	11.1	17.4
Signif.	NS	NS	NS	NS	NS
Radius (RAD; cm)					
0	119.1	17.7	2994	27.2	45.5
7.6	52.3	7.5	1285	14.2	22.0
15.2	40.4	5.1	930	9.9	15.2
22.9	42.3	5.0	989	9.8	15.0
30.5	46.7	5.6	1100	9.8	15.5
S X RAD	***	***	***	***	***

NS, *, **, ***Main effects and interactions were nonsignificant or significant at $P \leq$ 0.01, 0.001, respectively, according to F tests. Competition (7.6 to 30.5 cm RAD) vs no competition effects (0 RAD) were tested with contrasts. Radius effects were quadratic (Q) according to polynomial contrasts. Season by RAD interactions were determined with radii from 7.6 to 30.5 cm.

Table 3-7. Interaction of season and initial yellow nutsedge tuber circle radius on bell pepper leaf number, leaf dry weight, leaf area, stem dry weight, and total dry weight after pepper fruit harvest.

Season	Tuber circle radius (RAD; cm) 0	7.6	15.2	22.9	30.5	0 vs nutsedge	Nutsedge
			Pepper leaves (no.·plant^{-1})				
Spring	164.2	78.8	54.3	57.5	58.8	***	Q***
Fall	69.1	22.9	25.1	25.4	33.2	***	L**
			Pepper leaf dry wt (g·plant^{-1})				
Spring	21.5	11.3	7.2	6.9	6.9	***	Q***
Fall	13.5	3.3	2.8	3.0	4.2	***	Q*
			Pepper leaf area (cm^2·plant^{-1})				
Spring	3998	1974	1353	1396	1465	***	Q***
Fall	1879	518	459	537	694	***	L*
			Pepper stem dry wt (g·plant^{-1})				
Spring	38.8	22.5	15.3	15.0	13.9	***	Q**
Fall	12.7	3.7	3.2	3.2	4.6	***	NS
			Pepper total (leaf + stem) dry wt (g·plant^{-1})				
Spring	60.3	33.8	22.5	21.9	20.8	***	Q**
Fall	26.9	7.1	6.0	6.5	8.8	***	NS

NS, *, **, ***Row effects were nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001 according to F-tests. Competition (7.6 to 30.5 cm RAD) vs. no competition (0 RAD) effects were tested with contrasts. Significant tuber circle radius (7.5 to 30.5 cm) effects were linear (L) or quadratic (Q) according to polynomial contrasts.

Table 3-8. Main effects of year, season, yellow nutsedge tuber spacing within circles, and tuber circle radius on N concentration and uptake for harvested bell pepper fruit, leaf and stem tissue of pepper plants sampled after fruit harvest, and total N uptake.

	N conc. (% dry wt)			N uptake ($kg \cdot ha^{-1}$)			
Treatment	Fruit	Leaf	Stem	Fruit	Leaf	Stem	Total
Year (Y)							
1999	2.56	3.81	1.72	6.1	6.5	4.4	17.0
2000	2.18	2.58	1.07	8.3	3.1	2.8	15.1
Signif.					***		**
Season (S)							
Spring	2.77	2.97	1.31	10.6	5.9	5.2	21.7
Fall	1.94	3.50	1.52	3.3	3.7	1.7	9.1
Y X S		***	**	***	NS	*	NS
Tuber spacing (TS;							
5	2.17	3.24	1.36	3.9	3.2	2.5	9.9
10	2.48	3.17	1.35	5.2	3.4	2.6	11.6
Signif.		NS		**	NS	NS	*
S X TS		NS	*	NS	NS	NS	NS
Radius (RAD; cm)							
0	2.59	3.29	1.64	17.6	11.0	8.1	37.6
7.6	2.37	3.26	1.36	6.4	4.4	3.3	14.5
15.2	2.16	3.22	1.32	3.7	2.9	2.2	9.1
22.9	2.34	3.15	1.38	3.4	2.8	2.3	8.8
30.5	2.44	3.18	1.36	4.7	3.2	2.4	10.6
0 vs nutsedge		NS	***				
Nutsedge		NS	NS				
S X RAD		NS	NS	***	***	**	***
Y X S X TS X RAD	**	NS	NS	NS	NS	NS	NS

$^{NS, *, **, ***}$Effects were nonsignificant or significant at $P \leq 0.05, 0.01, 0.001$, respectively, according to F tests. Competition (7.6 to 30.5 cm RAD) vs. no competition (0 RAD) effects were tested with contrasts.

Table 3-9. Interaction of year and season on leaf and stem N concentration of bell pepper plants sampled after final fruit harvest.

	Season		
Year	Spring	Fall	
	Pepper leaf N conc (% dry wt)		Signif.
1999	3.29	4.33	***
2000	2.65	2.47	NS
Signif.	***	***	
	Pepper stem N conc (% dry wt)		Signif.
1999	1.51	1.92	**
2000	1.11	1.02	NS
Signif.	**	***	

NS, **, ***Column and row effects were nonsignificant or significant at $P \leq 0.01$ or 0.001 according to F-tests, respectively.

Table 3-10. Interaction of season and yellow nutsedge tuber spacing within circles on stem N concentration of bell pepper plants sampled after final fruit harvest.

	Tuber spacing (cm)		
Season	5	10	
	Pepper stem N conc (% dry wt)		Signif.
Spring	1.2	1.3	NS
Fall	1.5	1.4	NS
Signif.	**	NS	

NS, **Column and row effects were nonsignificant or significant at $P \leq 0.01$ according to F-tests, respectively.

Table 3-11. Interaction of year, season, yellow nutsedge tuber spacing within circles, and tuber circle radius on harvested bell pepper fruit N concentration.

			Tuber circle radius (cm)						
Year	Season	TS (cm)	0	7.6	15.2	22.9	30.5	0 vs. YNS[Z]	YNS[Z]
			Fruit N conc. (% dry wt)						
1999	Spring	5	2.4	2.6	2.8	2.4	2.6	NS	NS
1999	Spring	10	2.8	2.6	2.6	2.9	2.9	NS	L**
1999	Fall	5	2.7	2.8	1.1	1.9	2.7	NS	Q**
1999	Fall	10	2.8	2.6	2.6	2.7	2.6	NS	NS
2000	Spring	5	2.7	2.7	3.0	2.6	3.1	NS	C*
2000	Spring	10	2.9	3.1	2.6	3.0	3.0	NS	NS
2000	Fall	5	2.1	1.0	0.9	1.3	0	**	NS
2000	Fall	10	2.0	1.0	1.3	1.5	1.9	NS	NS

[Z]Yellow nutsedge (YNS) radius competition (7.6 to 30.5 cm radius) vs. no competition (0 radius) effects were tested with contrasts. Significant YNS radius (from 7.6 to 30.5 cm) effects were linear (L), quadratic (Q), or cubic (C) according to polynomial contrasts.

[NS, *, **]Effects were nonsignificant or significant at $P \leq 0.05$ or 0.01, respectively, according to F-tests.

Table 3-12. Interaction of year and season on N uptake by harvested bell pepper fruit and stem tissue of pepper plants sampled after final fruit harvest.

	Season		
Year	Spring	Fall	
	Fruit N uptake ($kg \cdot ha^{-1}$)		Signif.
1999	8.52	3.76	***
2000	12.77	2.77	***
Signif.	***	NS	
	Stem N uptake ($kg \cdot ha^{-1}$)		Signif.
1999	6.51	2.21	***
2000	3.93	0.85	***
Signif.	***	**	

NS, **, ***Effects were nonsignificant or significant according to F-tests with analysis of variance, respectively.

Table 3-13. Interaction of season and initial yellow nutsedge tuber circle radius on uptake of N by harvested bell pepper fruit, above ground leaf and stem tissue of plants sampled after final fruit harvest, and N taken up by harvested fruit and pepper leaf and stem tissue.

	Tuber circle radius (cm)						
Season	0	7.6	15.2	22.9	30.5	0 vs. nutsedge[Z]	Nutsedge[Z]
				Fruit N uptake ($kg \cdot ha^{-1}$)			
Spring	24.2	10.8	6.1	5.4	6.7	***	Q***
Fall	10.3	1.6	1.1	1.2	2.5	***	Q**
				Leaf N uptake ($kg \cdot ha^{-1}$)			
Spring	12.1	6.3	3.9	3.5	3.6	***	Q***
Fall	9.7	2.2	1.9	2.0	2.8	***	NS
				Stem N uptake ($kg \cdot ha^{-1}$)			
Spring	11.0	5.1	3.3	3.4	3.3	***	Q**
Fall	4.4	1.0	0.84	0.93	1.26	***	NS
				Total (fruit + leaf + stem) N uptake ($kg \cdot ha^{-1}$)			
Spring	47.3	22.2	13.2	12.3	13.7	***	Q***
Fall	25.5	4.9	4.0	4.3	6.8	***	Q*

[Z]Nutsedge competition (7.6 to 30.5 cm radius) vs. no competition (0 radius) effects were tested with contrasts.

[NS, *, **, ***]Effects were nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001 according to F-tests. Significant tuber circle radius (7.6 to 30.5 cm) were quadratic according to polynomial contrasts.

Table 3-14. Main effects of year, season, tuber spacing within circles, and tuber circle radius on yellow nutsedge shoot height, number, and dry weight during bell pepper flowering (1), fruit development (2), or after final fruit harvest (3).

	Nutsedge						
	Ht (cm)			Shoot no.· cir.$^{-1}$ z			g dry wt·cir.$^{-1}$
Treatment	1	2	3	1	2	3	3
Year (Y)							
1999	52	65	64	--	432	595	585
2000	50	76	74	--	561	444	300
Season (S)							
Spring	38	78	84	271	723	847	661
Fall	65	61	53	295	238	164	216
Y X S			***	--	***		
Tuber spacing (TS; cm)							
5	53	70	68	290	527	553	467
10	49	70	70	280	460	494	433
Signif.		NS		--	**	NS	NS
Y X TS		NS	*	--	NS	NS	NS
S X TS		NS	*	--	NS	NS	NS
Radius (RAD; cm)							
7.6	50	70	69	133	272	290	257
15.2	52	70	71	240	486	541	469
22.9	51	71	70	331	534	541	469
30.5	50	68	66	436	681	723	605
Signif.			Q***	--			
Y X RAD			NS	--	***		
S X RAD			NS	--	***		
Y X S X RAD		*	NS	--	NS	**	**
Y X S X TS X RAD	**	NS	NS	--	NS	NS	NS

[Z]Data expressed on a per circle (cir.) basis. Shoot numbers at pepper flowering were not obtained in spring 1999, so data were not analyzed.

[NS, *, **, ***]Effects were nonsignificant or significant at $P \leq 0.05, 0.01, 0.001$, respectively, according to F tests. Tuber circle radius effect on height at 3 WAT was quadratic (Q) according to a polynomial contrasts.

Table 3-15. Interaction of year and season on yellow nutsedge shoot height after final fruit harvest and shoot number during bell pepper fruit development.

	Season		
Year	Spring	Fall	
	Nutsedge ht (cm)		Signif.
1999	81	48	***
2000	86	59	***
Signif.	**	***	
	Nutsedge number ($no \cdot cir^{-1}$)		Signif.
1999	170	34	***
2000	159	81	***
Signif.	NS	***	

NS, **, ***Column and row effects were nonsignificant or significant at $P \leq 0.01$ or 0.001, respectively, according to F-tests.

Table 3-16. Interaction of year and yellow nutsedge tuber spacing within circle on nutsedge shoot height after final bell pepper fruit harvest.

	Tuber spacing (cm)		
Year	5	10	Signif.
1999	64	65	NS
2000	72	76	*
Signif.	***	***	

NS,*, ***Column and row effects were nonsignificant or significant at $P \leq 0.05$ or 0.001 according to F-tests., respectively.

Table 3-17. Interaction of season and yellow nutsedge tuber spacing within circle on nutsedge shoot height after final bell pepper fruit harvest.

	Tuber spacing (cm)		
Season	5	10	Signif.
Spring	82	86	**
Fall	53	53	NS
Signif.	***	***	

NS, **, ***Column and row effects were nonsignificant or significant at $P \leq 0.01$ or 0.001, respectively, according to F-tests.

Table 3-18. Interaction of year, season, yellow nutsedge tuber spacing within circles, and tuber circle radius on nutsedge shoot height during bell pepper flowering.

			Tuber circle radius (cm)				
Year	Season	Tuber spacing (cm)	7.6	15.2	22.9	30.5	Signif.
			Nutsedge ht (cm)				
1999	Spring	5	46	46	44	44	L**
1999	Spring	10	40	39	40	38	NS
1999	Fall	5	63	64	61	60	L*
1999	Fall	10	61	62	65	60	Q*
2000	Spring	5	36	39	33	34	C*
2000	Spring	10	33	33	33	32	NS
2000	Fall	5	67	69	73	75	L**
2000	Fall	10	63	69	67	67	NS

[Z]Yellow nutsedge competition (7.6 to 30.5 cm radius) vs. no competition (0 radius) effects were tested with contrasts.

NS, *, **Effects were nonsignificant or significant at $P \leq 0.05$ or 0.01, respectively, according to F-tests. Significant radius (from 7.6 to 30.5 cm) effects were linear (L), quadratic (Q), or cubic (C) according to polynomial contrasts.

Table 3-19. Interaction of year, season, and initial yellow nutsedge tuber circle radius on nutsedge shoot height during pepper fruit development and on nutsedge shoot number, dry weight, and N uptake after pepper fruit harvest.

		Tuber circle radius (cm)				
Year	Season	7.6	15.2	22.9	30.5	Signif.
		Nutsedge ht (cm) at pepper fruit development				
1999	Spring	71	73	72	73	C*
1999	Fall	59	57	58	53	NS
2000	Spring	85	84	83	84	C*
2000	Fall	64	67	68	63	Q**
		Nutsedge shoots at pepper fruit harvest ($no \cdot circle^{-1}$)				
1999	Spring	559	1067	1182	1478	L***
1999	Fall	81	102	152	136	L*
2000	Spring	371	717	553	850	C***
2000	Fall	112	213	210	351	L***
		Nutsedge dry wt at pepper fruit harvest ($g \cdot cir^{-1}$)				
1999	Spring	483	1040	909	1288	C*
1999	Fall	163	225	313	260	NS
2000	Spring	243	391	418	518	L***
2000	Fall	111	156	180	293	L***
		Nutsedge N uptake at pepper fruit harvest ($kg \cdot ha^{-1}$)				
1999	Spring	112	257	213	286	C*
1999	Fall	28	35	51	44	NS
2000	Spring	40	67	67	87	C*
2000	Fall	13	19	22	35	L***

NS, *, **, ***Effects were nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively, according to F-tests. Significant radius effects were linear (L) or cubic (C) according to polynomial contrasts.

Table 3-20. Interaction of year and initial yellow nutsedge tuber circle radius on nutsedge shoot number per circle during bell pepper fruit development.

	Tuber circle radius (cm)				
Year	7.6	15.2	22.9	30.5	Signif.
	Nutsedge shoots (no.·circle^{-1})				
1999	262	466	459	542	C**
2000	284	508	618	836	L***

**, ***Row effects were significant at P ≤ 0.01 or 0.001 according to F-tests. Tuber circle radius were linear (L) or cubic (C) according to polynomial contrasts.

Table 3-21. Interaction of season and initial yellow nutsedge tuber circle radius on nutsedge shoot number per circle during bell pepper fruit development.

	Tuber circle radius (cm)				
Season	7.6	15.2	22.9	30.5	Signif.
	Nutsedge shoots (no·circle^{-1})				
Spring	385	737	773	999	C**
Fall	147	207	268	327	L***

**, ***Row effects were significant at P ≤ 0.01 or 0.001 according to F-tests. Tuber circle radius were linear (L) or cubic (C) according to polynomial contrasts.

Table 3-22. Main effects of year, season, yellow nutsedge tuber spacing within circles, and tuber circle radius on nutsedge shoot N concentration and N uptake after final bell pepper fruit harvest.

	Nutsedge	
Treatment	N conc. (% dry wt.)	N uptake ($kg \cdot ha^{-1}$)
Year (Y)		
1999	1.1	128.1
2000	0.8	46.1
Signif.	***	
Season (S)		
Spring	1.1	141.1
Fall	0.8	31.6
Signif.	***	
Y X S	NS	
Tuber spacing (TS; cm)		
5	1.0	90.8
10	1.0	87.7
Signif.	NS	NS
Radius (RAD; cm)		
7.6	1.0	50.0
15.2	1.0	98.5
22.9	1.0	91.6
30.5	0.9	116.9
Signif.	NS	
Y X S X RAD	NS	*

NS, *, ***Main effects and interactions were nonsignificant or significant at $P \leq 0.05, 0.001$, respectively, according to F tests from analysis of variance.

CHAPTER 4
EFFECT OF 1,3-D + CHLOROPICRIN AND METAM-NA ON YELLOW NUTSEDGE TUBERS GROWN IN A GREENHOUSE AT DIFFERENT GROWTH STAGES

Introduction

Soil-borne pests including nutsedge tubers are prevalent in Florida soils. Nutsedge is difficult to control because it propagates via underground tubers which often escape the effects of applied chemicals. Each nutsedge tuber has multiple (two to seven) buds (Tumbleson and Kommedahl, 1961), each of which must be killed to prevent tuber sprouting. Competition from uncontrolled nutsedge has substantially reduced vegetable yields (Buker III et al., 1998; Morales-Payan et al., 1998; William and Warren, 1975)

Before the use of broad-spectrum soil fumigants, vegetable growers avoided or minimized competition from soil pathogens and weeds by using new land. With the introduction of broad-spectrum soil fumigants and polyethylene mulch, successive crops were grown on the same land. Since the early 1970's, most Florida vegetable growers have relied on methyl bromide or methyl bromide-chloropicrin combinations as the primary means of nutsedge control in polyethylene-mulched vegetable production. Methyl bromide is easy to apply and has strong activity against soil pests including nutsedge under a wide range of conditions (Bewick, 1980; Noling and Becker, 1994; Overman and Martin, 1978; Williamson et al., 1955).

Methyl bromide is being phased out of production due to its alleged contribution to stratospheric ozone depletion (Environmental Protection Agency, 1999; Watson et al.,

1992). Metam-Na and 1,3-dichloropropene (1,3-D) are two commercially available chemical alternatives. Metam-Na produces a vapor called methyl isothiocyanate (MITC) that is lethal to soil organisms including weeds while 1,3-D is primarily a nematicide. Usually 1,3-D is combined with chloropicrin (Pic) for disease control.

The activity of metam-Na on nutsedge has been mixed. Gilreath et al. (1995) found that purple nutsedge control with metam-Na + pebulate was equal to that obtained with methyl bromide. Csinos et al. (2000) showed that metam-Na (468 $L \cdot ha^{-1}$) + 1, 3-D with 17 % Pic (126 $L \cdot ha^{-1}$) provided good control of most pests in pepper transplant production fields when covered with polyethylene film immediately after treatment. Olson et al. (1996), on the other hand, found that metam-Na + pebulate did not reduce yellow and purple nutsedge infestations compared to those found in untreated plots. Jaworski et al. (1980) and Locascio et al. (1997) found that metam-Na + pebulate was less effective than methyl bromide in controlling nutsedge in pepper transplant and tomato production fields, respectively.

Activity of 1,3-D + Pic against nutsedge has been minimal (Gilreath et al., 1994; Locascio et al., 1997; Stall, 1994). Combinations of 1,3-D + Pic with pebulate, however, have been efficacious against nutsedge (Gilreath et al., 1994; Locascio et al., 1997), and 1,3-D + Pic + pebulate is the leading methyl bromide alternative for polyethylene-mulched tomato production.

Studies have shown that nutsedge is most susceptible to chemical control when actively growing (Cools and Locascio, 1977; Doll and Piedrahita, 1978; Fraedrich et al., 2002; Zandstra and Nishimoto, 1977). Therefore, this experiment was conducted to test

the hypothesis that poor or erratic performance of metam-Na and 1,3-D + Pic with respect to yellow nutsedge control was due to the presence of tubers at varying stages of growth.

Materials and Methods

Treatment Design

Greenhouse studies were conducted in Gainesville, Fla, with a study at the University of Fla. campus and the Horticulture Unit in spring 2000 and winter 2001, respectively. In spring 2000, treatments were three fumigation treatments [no fumigation, 1,3-D + 35% Pic at 327 $L \cdot ha^{-1}$, metam-Na at 294 $L \cdot ha^{-1}$], two tuber sources (Gainesville and Quincy), and three tuber growth stages (dry, water imbibed, and sprouted). In winter 2001, dry and water-imbibed tubers were used. During both seasons, two outlier treatments (metam-Na at 147 $L \cdot ha^{-1}$ and metam-Na at 589 $L \cdot ha^{-1}$ applied to imbibed tubers) were also included. Treatments were replicated six times and arranged in a split plot design with tuber sources as whole plots. Fumigant rates were calculated based on the surface area of plastic pans (35.6 cm long X 24.1 cm wide X 15.2 cm deep) used to hold soil and tubers.

Experiment Establishment

Yellow nutsedge tubers from Gainesville were collected at the Horticulture Unit on 2 March in spring 2000 and on 5 Feb. in winter 2001 in fields with native and 'Chufa' (*Cyperus esculentus* var. *sativus*) tubers. On the day Gainesville tubers were collected, tubers from Gainesville and 'Chufa' tubers from Quincy, Fla. were washed, dried, and stored at 10 °C. Tubers were imbibed with water for approximately 26 hours at 25 °C by placing them between moistened paper towels. Sprouted tubers in spring 2000 were

obtained by imbibing with water in the same manner as above for one week resulting in 2.5 to 5 cm long rhizomes.

Soils (Kanapaha fine sand in spring 2000 and Arredondo fine sand in winter 2001) from the Horticulture Unit in Gainesville, Fla. were sifted with a screen to exclude nutsedge tubers. Treatments were applied 9 March (spring 2000) and 8 Feb.(winter 2001). Nutsedge-free soil was mixed with water (to bring soil to near field capacity) and NH_4NO_3 (at 112 $kg \cdot ha^{-1}$ N) without (untreated check) or with metam-Na in a cement mixer. Pans were filled with 7.6 cm of soil (treated or untreated for metam-Na and 1,3-D + Pic treatments, respectively) and a plastic pot label was placed in the center of each pan. On either side of the pot label, 20 Gainesville and 20 Quincy tubers were placed on the soil surface. Pans were covered with an additional 6.4 cm of soil (treated or untreated for metam-Na and 1,3-D + Pic treatments, respectively). A syringe with a hypodermic needle was used to inject 1,3-D + Pic (after planting and filling pans with soil) in four equal amounts near the corners of each soil-filled pan. Immediately after treatment application and tuber planting, each pan was sealed with black plastic secured by a rubber band. A white, flat plastic lid was placed on each pan.

Three days after treatment application, pan covers were removed. Pans received water as needed via overhead sprinkling with a hose. Near the end of each experiment, several randomly selected tubers subjected to metam-Na and 1,3-D + Pic were dug up and examined. The experiment was terminated when they were consistently found to be in a state of decomposition. The experiment was terminated 28 and 44 days after planting (DAP) in spring 2000 and winter 2001, respectively.

Data Collection and Analysis

Minimum and maximum daily temperatures were obtained with a minimum-maximum thermometer (Taylor; Arden, North Carolina) placed on the top of one of the pans. Nutsedge shoots were counted every four days beginning on the day pans were uncovered. Yellow nutsedge control was estimated by dividing the number of shoots in fumigated pans by the number of shoots in non-fumigated pans and subtracting the resulting percentage from 100. Data were analyzed via ANOVA in SAS. Temperatures and the number of shoots emerged from untreated tubers were plotted over time.

Results and Discussion

In spring 2000, none of the tubers in pans receiving either 1,3-D + Pic or metam-Na produced shoots. Three weeks after planting, tubers in fumigated pans were dead. Therefore, no statistics were generated for data obtained during spring 2000. It appeared that 100% of the untreated tubers had germinated by 28 March (Fig. 4-1).

At 28 DAP in winter 2001, approximately 25 shoots had emerged in pans with untreated dormant and imbibed tubers (Fig. 4-1), suggesting that most or all of the 20 planted Gainesville or Quincy tubers had germinated in each pan. None of the tubers that were fumigated with metam-Na, however, produced shoots. Six weeks after planting, metam-treated tubers were dead. Therefore, metam-Na consistently controlled yellow nutsedge regardless of fumigant rate or tuber growth stage.

A few shoots emerged from tubers fumigated with 1, 3-D + Pic in winter 2001. Because no shoots emerged from tubers treated with metam-Na in spring 2000 and in winter 2001 or from tubers treated with 1, 3-D + Pic in spring 2000, statistics were generated only for 1-3, D + Pic effects on tuber sprouting in winter 2001 (Table 4-1).

Tuber source had no influence on percent control of nutsedge shoot emergence with 1, 3-D + Pic in winter 2001 (data not shown). By 40 DAP tubers planted dry and imbibed produced 7 and < 1 shoot(s)·pan^{-1}, respectively, while untreated tubers produced 30 shoots·pan^{-1}. At 20, 28, 40, and 40 DAP, 1,3-D + Pic provided greater control of tubers that were water-imbibed than dry at planting at $P \leq 0.13$ (Table 4-1).

Activity of 1, 3-D + Pic against nutsedge was probably greatest during the first two days after soil application. Ajwa and Trout (2001) monitored soil gas concentrations of 1,3-D following 10 days of soil fumigation through drip lines. Concentrations of 1, 3-D in soil gas at 10, 20, 30, 40 and 60 cm depths was greatest 24 to 36 hours after fumigant application. Concentration of 1,3-D in soil gas was below detection limits at 14 days after application.

In the present study, out-gassing was minimized during the first three days after fumigant application due to the absence of holes in pans and the covering of pans with polyethylene film and pan lids. Therefore, total prevention of nutsedge shoot emergence with 1, 3-D + Pic in spring 2000 but not in winter 2001 was likely an effect of climatic conditions influencing the performance of 1,3-D + Pic during the first 24 hours after experiment establishment.

In both years, 1,3-D + Pic was applied before noon on the day of fumigant application, and minimum early-morning air temperature that day was 12.4 °C in 2000 compared to 3.8 °C in 2001 (data not shown). The soil was probably warmer, therefore, in spring 2000 than in winter 2001 when 1,3-D + Pic was applied . On the day of fumigant application, maximum air temperatures in the greenhouse were slightly greater in spring 2000 than in winter 2001 (Fig. 4-2). Furthermore, air temperature dropped to

6 °C in winter 2001 compared to 15 °C in the morning of the following day (Fig. 4-2). Therefore temperatures were greater in spring 2000 than winter 2001 during the first day of the experiment, and this accounted for greater activity of 1, 3-D + Pic in spring 2000 than in winter 2001 because the diffusion of fumigant gas increases with increased temperature. Results indicated that the activity of 1, 3-D + Pic against yellow nutsedge tubers was temperature dependent.

Greater activity of 1, 3-D in winter 2001 against imbibed than dry tubers (Table 4-1) was consistent with reports that glyphosate was most active against nondormant tubers (Cools and Locascio, 1977; Doll and Piedrahita, 1978; Fraedrich et al., 2002; Zandstra and Nishimoto, 1977;). For instance, Cools and Locascio (1977) found that glyphosate controlled purple nutsedge more effectively in summer and fall than in spring seasons due to tuber dormancy in the spring. In the present study, it seemed likely that the metabolic activity of tubers planted without prior water imbibition was less than that of imbibed tubers rendering dry tubers less susceptible to 1,3-D + Pic than imbibed tubers.

On the 4th day after experiment establishment, a few shoots had emerged in spring 2000 compared to no shoots in winter 20001 (Fig. 4-1). This was possibly due to the minimum temperature of 6 °C on the day after fumigant application in winter 2001 (Fig. 4-2). Although yellow nutsedge tubers can sprout at temperatures as low as 6 °C (Holt and Orcutt, 1996), they are more likely to germinate when soil temperatures reach 12 °C or more. Germination is maximized at temperatures of 25 °C (Stoller and Wax, 1973). In winter 2001, the low air temperature of 6 °C may have resulted in soil temperatures below 12 to 25 °C, thereby slowing tuber sprouting and subsequent shoot emergence.

Both chemicals provided total or near total control of yellow nutsedge for 1 month regardless of tuber growth stage (data for 1,3-D + Pic shown in Table 4-1). This degree of activity against yellow nutsedge has not been observed in the field (Gilreath et al, 1994; Locascio et al., 1997; Olson et al. 1996). In the present greenhouse study, total or near total control of yellow nutsedge with metam-Na and 1, 3-D + Pic for 28 days was likely a result of minimizing the escape of fumigant gasses from polyethylene-covered pans.

Thus, it may be possible to enhance the effectiveness of metam-Na and 1, 3-D + Pic by adopting production practices such as the use of virtually impervious film to minimize volatilization of fumigant gasses. Ajwa and Trout (2001) found that concentrations of 1,3-D in the gaseous phase of a Watsonville soil 24 hours after application was at least 40% greater under virtually impermeable than standard polyethylene film. Locascio et al. (2001) found, however, that covering soil-injected 1,3-D + Pic (17%) with virtually impermeable film did not improve nutsedge control with 1,3-D + Pic (17%) relative to that provided by standard polyethylene film. Their results also indicated that minimizing the escape of fumigant gasses from planting beds may result in crop injury if the time interval between fumigant application and crop planting is too short. More research is needed to identify methods to maximize fumigant gasses near nutsedge tubers without inducing crop injury.

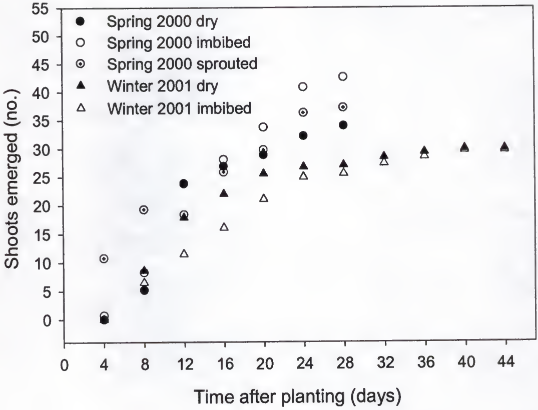


Fig. 4-1. Number of shoots emerged at four-day intervals from untreated dry, sprouted, or imbibed tubers planted in spring 2000 and winter 2001.

Table 4-1. Main effects of tuber growth stage and tuber source on percent control with 1,3-D of yellow nutsedge shoot emergence in winter 2001.

	Time after tuber planting and fumigation (days)							
Treatment	16	20	24	28	32	36	40	44
	Shoots emerged with no fumigation (no.·pan^{-1})^{Z}							
Tuber stage								
Dry	22	26	27	27	28	30	30	30
Imbibed	16	21	25	26	27	29	30	30
	Shoots emerged with 1, 3-D + Pic (no.·pan^{-1})^{Z}							
Tuber stage								
Dry	0.4	1.0	2	2.8	3.0	6	6	7
Imbibed	0.2	0.3	0.3	0.5	0.6	0.7	0.7	0.8
	Control of shoot emergence (%)							
Tuber stage								
Dry	97.8	95.3	92.0	89.1	88.7	79.5	77.3	74.9
Imbibed	98.3	98.5	98.5	97.8	97.6	97.2	97.4	96.8
Signif.	NS	X	NS	X	NS	NS	X	X

^{Z}Shoot numbers were shown but not analyzed.

$^{NS,\ X}$Effects were nonsignificant or significant at $P \leq 0.13$, respectively, according to F-tests.

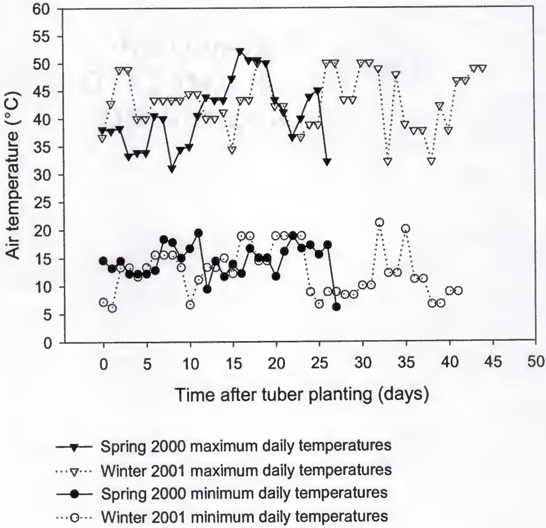


Fig. 4-2. Minimum and maximum daily air temperatures from experiment establishment to termination time in spring and winter of 2001.

CHAPTER 5
SUMMARY AND CONCLUSIONS

Bell pepper is a major Florida vegetable crop with over 7,400 ha planted annually between 1984 and 1999 (Witzig and Pugh, 2000). In 1998, the total value of bell peppers produced in the state, $243 million, ranked second to that of tomato. Most of the bell peppers produced in Florida are field-grown on fumigated raised beds covered with polyethylene mulch. With no effective fumigant, nutsedge rhizome tips arising from underground tubers easily penetrate polyethylene mulch and become established in planting beds.

Once established, nutsedge has the capacity to significantly reduce crop yields. For instance, season-long interference of purple nutsedge (*Cyperus rotundus* L.) reduced greenhouse-grown bell pepper fruit yield by 73% (Morales-Payan et al., 1998) and 32% (Morales-Payan et al., 1997). Yield of field-grown okra and tomato was reduced 62% and 53%, respectively, by season-long interference of purple nutsedge. (William and Warren, 1975). Yellow nutsedge interference reduced watermelon fruit yields by up to 98% (Buker III et al., 1998).

Methyl bromide fumigant effectively controls nutsedge but is being phased out of use (Environmental Protection Agency, 1999; Watson et al., 1992). Furthermore, there are no herbicides labeled for pepper that provide acceptable nutsedge control. Therefore, nutsedge control in bell pepper fields is expected to be a major concern.

In developing an integrated approach to yellow nutsedge control in bell pepper production fields, several thresholds must be determined. These include the number of yellow nutsedge tubers resulting in an economically acceptable amount of bell pepper fruit yield loss (defined as 10% in Chapter 1), the critical weed-free period during which nutsedge must be controlled (Chapter 2), and the distance of tubers from a pepper plant at which nutsedge must be controlled (Chapter 3). These thresholds had not been determined for yellow nutsedge and field-grown bell pepper.

Results from the nutsedge tuber population study (Chapter 1) showed that bell pepper biomass and fruit yield reduction by nutsedge interference increased with an increase in planted yellow nutsedge tuber density from 0 to 90 (fall 1999 and spring and fall of 2000) or 120 tubers$\cdot m^{-2}$ (spring 1999) The critical density for 10% bell pepper fruit yield loss was reached with interference by nutsedge plants from less than 5 tubers$\cdot m^{-2}$. Furthermore, pepper fruit yield losses of at least 50% were observed when 30 tubers$\cdot m^{-2}$ were planted. Thus, bell pepper was not tolerant of yellow nutsedge, and any control measure would need to provide near total control of yellow nutsedge.

Reducing pepper plant spacing from 31 to 23 cm increased the number of pepper plants competing with nutsedge (Chapter 1). This improved competitiveness of pepper against nutsedge in spring seasons. Regardless of in-row pepper spacing, however, pepper fruit weight losses (%) were high.

Substantial reductions in bell pepper growth and fruit yields by season-long nutsedge interference, even with as low as 10 and 15 tubers$\cdot m^{-2}$, indicated that nutsedge competed strongly with pepper for common resources. Moisture was supplied daily to prevent pepper and nutsedge plants from wilting. In one instance (Table 1-33), increases

in initial tuber population decreased pepper plant N concentration, indicating that nutsedge competed with pepper for N. The amount of N concentrated in pepper plants exceeded that reported to be deficient for pepper growth (Lorenz and Maynard, 1988) probably because 40% of the fertilizer N was supplied at weekly intervals via fertigation. Therefore, pepper plant N concentration data did not conclusively show that N was the main resource being competed for. Competition for sulfur was observed in spring 1999, but pepper plants grown with nutsedge recovered after fertigation with $(NH_4)_2SO_4$. Symptoms of deficiencies of other nutrients in pepper plants were not observed.

Bell pepper and yellow nutsedge growth parameter data indicated that light was the most limiting resource for bell pepper grown with nutsedge. For example, during pepper flowering in spring seasons, pepper plant height increased with an increase in tuber density from 0 to 90 or 120 tubers$\cdot$m^{-2} (Tables 1-6 and 1-9). Furthermore, yellow nutsedge shoots grew taller than bell pepper plants, and yellow nutsedge leaf blades intercepted more than 40% of the sunlight at pepper flowering during spring and fall 2000 (Fig. 1-9).

Season-long yellow nutsedge interference substantially reduced the biomass of pepper leaves, stems, and fruit (Chapter 1). Therefore, pepper plants were not able to compensate for nutsedge interference by partitioning dry matter into fruit instead of vegetative tissue.

To determine the critical yellow-nutsedge-free period for bell pepper fruit production, the biological threshold had to be determined to avoid underestimating the time span that yellow nutsedge must be controlled. The biological threshold was reached with 30 to 45 tubers$\cdot$m^{-2} because pepper plant fruit yield losses increased more sharply

with an increase in tuber density from 0 to 30 or 45 than from 45 to 90 or 120 tubers·m^{-2} (Chapter 1). Therefore, critical period studies were conducted with a constant tuber density of 45 tubers·m^{-2} (Chapter 2).

As shown in Chapter 2, yellow nutsedge would need to be controlled for a longer period of time in fall than spring. For instance, without losing greater than 10% of marketable fruit weight to yellow nutsedge interference, a nutsedge-free period of 4 to 5 and 1½ to 6½ WAT was required for the spring and fall pepper crop, respectively. Nutsedge height, shoot number, and biomass data showed that this was due to greater early-season nutsedge growth and vigor in fall than spring.

In addition to the extent and duration of nutsedge control, it is also important to know the distance between a bell pepper plant and yellow nutsedge tubers at which pepper plant growth and fruit production is reduced. This was addressed in Chapter 3. Nutsedge interference was maximized when planted at a distance from pepper that resulted in maximum nutsedge leaf blade coverage of bell pepper plants. This distance of planted tubers from a pepper plant was 22.9 cm in spring seasons and 7.6 to 22.9 cm in fall 1999 (Fig. 3-1). Nutsedge interference, with tubers spaced 5 or 10 cm apart, substantially reduced bell pepper plant growth and fruit production with all initial distances (7.6 to 30.5 cm) between nutsedge tubers and a bell pepper plant.

The tuber density per nutsedge circle of at least 65 tubers·m^{-2} exceeded the biological threshold of 30 to 45 tubers·m^{-2} determined in the tuber population experiment (Chapter 1). This accounted for high bell pepper biomass and fruit yield losses to nutsedge interference with all initial nutsedge tuber circle sizes. With an initial yellow nutsedge plant density from 65 tubers·m^{-2}, therefore, increasing the distance from a

pepper plant from 7.6 to 30.5 cm did not reduce the ability of nutsedge plants to strongly compete with bell pepper. It would not be uncommon for nutsedge tubers in vegetable production fields to occur within 5 to 10 cm of each other, resulting in tuber densities of $\geq$ 65 tubers$\cdot$m^{-2}. Results indicated, therefore, that yellow nutsedge would need to be controlled to the edges of 61-cm-wide planting beds.

Results from the distance experiment (Chapter 3) indicated that the allelopathic potential of yellow nutsedge was not the main factor influencing pepper plant growth and yield reductions. If allelopathy were an important factor influencing crop performance, nutsedge planted close to pepper plants in spring seasons would likely have reduced yields to a greater extent than nutsedge planted further from pepper plants; however, as shown in Fig 3-1, this did not occur.

Except for nutsedge planted after bell pepper transplanting (Chapter 2), yellow nutsedge shoots were taller than bell pepper plants by as early as pepper flowering in the tuber population (Chapter 1), critical period (Chapter 2), and distance (Chapter 3) experiments. Thus, in each of the above experiments, yellow nutsedge appeared to interfere with bell pepper growth by competing for light. It was shown that, at pepper flowering 6 WAT, nutsedge leaf blades intercepted at least 40% of available light with 90 planted tubers$\cdot$m^{-2} (Fig. 1-10).

Early-season yellow nutsedge growth and vigor were greater in fall than spring seasons (Chapters 1, 2, and 3). In each of the above experiments, for instance, nutsedge shoots were taller in fall than spring at pepper flowering. Late-season yellow nutsedge growth and vigor were greater in spring than fall due to declining daylength over time in fall seasons (Chapters 1, 2, and 3). Because pepper plants produced less biomass and

fruit (Chapters 1, 2, and 3) in fall than spring seasons, bell pepper growth and yields were influenced more by early- than late-season yellow nutsedge growth and vigor. Early-season yellow nutsedge control would be important for spring- and fall-grown bell pepper, especially for satisfactory fruit yield with a fall-season pepper crop. In addition, any yellow nutsedge management strategy would need to provide greater control of yellow nutsedge in fall-than spring-season pepper production fields.

Chemicals including metam-Na and 1,3-D + Pic are expected to be important alternatives to methyl bromide for controlling yellow nutsedge in bell pepper. When kept near the tubers in plastic pans, metam-Na provided 100% control of yellow nutsedge while 1,3-D + Pic provided 100% in spring 2000 and 90% control in winter 2001 28 DAP (Chapter 4). In winter 2001, 1,3-D + Pic provided greater control of tubers that had been imbibed with water than those planted dry. Therefore, minimizing the escape of metam and 1,3-D vapors from bell pepper planting beds and applying when tubers are ready to sprout or sprouting would be expected to increase the activity of these chemicals against yellow nutsedge.

APPENDIX A
SPATIAL PATTERN OF PLANTED TUBERS IN TUBER POPULATION EXPERIMENT

$120 \cdot m^{-2}$

X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

$90 \cdot m^{-2}$

X	X	X		X	X	X		X	X	X		X	X	X		X
	X	X	X		X	X	X		X	X	X		X	X	X	
		X	X	X		X	X	X		X	X	X		X	X	X
X	X		X	X	X		X	X	X		X	X	X		X	X

$60 \cdot m^{-2}$

X		X		X		X		X		X		X		X		X
	X		X		X		X		X		X		X		X	
X		X		X		X		X		X		X		X		X
	X		X		X		X		X		X		X		X	

$30 \cdot m^{-2}$

X				X				X				X				X
	X				X				X				X			
		X				X				X				X		
			X				X				X				X	

Fig. A-1. Spatial pattern of yellow nutsedge tubers with densities used in spring 1999. A planted tuber is indicated by 'X'.

90·m^{-2}

X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

60·m^{-2}

X	X		X	X		X	X		X	X		X	X		X	X
	X	X		X	X		X	X		X	X		X	X		X
X		X	X		X	X		X	X		X	X		X	X	
X	X		X	X		X	X		X	X		X	X		X	X

45·m^{-2}

X		X		X		X		X		X		X		X		X
	X		X		X		X		X		X		X		X	
X		X		X		X		X		X		X		X		X
	X		X		X		X		X		X		X		X	

30·m^{-2}

X			X			X			X			X			X	
	X			X			X			X			X			X
		X			X			X			X			X		
X			X			X			X			X			X	

20·m^{-2}

X				X					X				X			
		X				X					X				X	
				X				X					X			
	X					X				X					X	
			X					X				X				

15·m^{-2}

X						X						X				
			X						X						X	
X						X						X				
			X						X						X	

10·m^{-2}

X									X							
				X									X			
								X								
			X									X				

Fig. A-2. Spatial pattern of yellow nutsedge tubers with densities used in fall 1999 and spring and fall 2000. A planted tuber is shown by 'X'.

APPENDIX B
FRUIT NUMBER DATA

Additive Studies

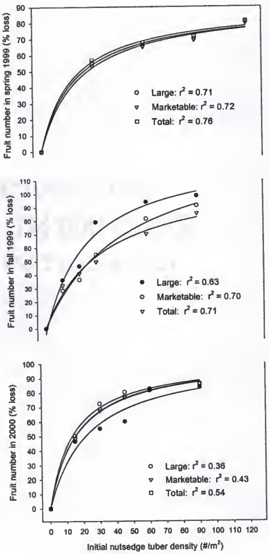


Fig. B-1. Main effect of initial yellow nutsedge tuber density on loss of large, marketable, or total bell pepper fruit number, relative to number obtained with no nutsedge, in spring 1999, fall 1999, and in 2000 (spring and fall data combined). Coefficients of determination (r^2 values) were determined by regressing data within means (shown). Models were significant at $P \leq 0.001$.

Table B-1. Coefficients for the rectangular hyperbola [$Y = ID/(1 + ID/A)$] used to characterize the effect of initial yellow nutsedge tuber density on reduction (%) of bell pepper fruit number in spring 1999, fall 1999, and in spring and fall of 2000.

	Parameter[z]	
Pepper fruit grade	I	D
	Spring 1999	
Large	0.05 ± 0.01	86.5 ± 6.2
Marketable	0.04 ± 0.01	86.3 ± 6.9
Total	0.06 ± 0.02	82.5 ± 5.0
	Fall 1999	
Large	0.04 ± 0.01	132.5 ± 13.8
Marketable	0.02 ± 0.006	142.2 ± 18.9
Total	0.03 ± 0.01	113.0 ± 10.7
	Spring and fall 2000	
Large	0.07 ± 0.02	101.9 ± 7.1
Marketable	0.06 ± 0.01	102.9 ± 6.8
Total	0.06 ± 0.01	103.4 ± 5.5

[z]Coefficients ± standard errors for each variable were obtained with data within means. Models were significant at $P \leq 0.001$.

Critical Period Studies

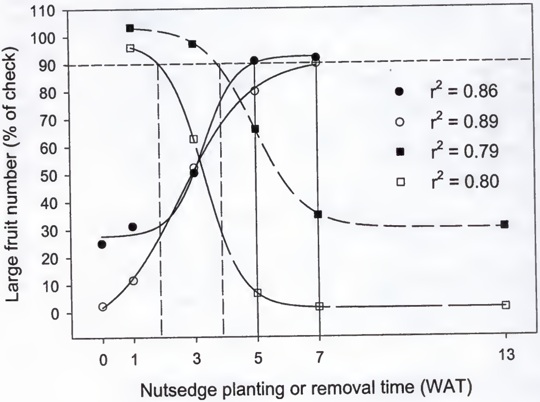
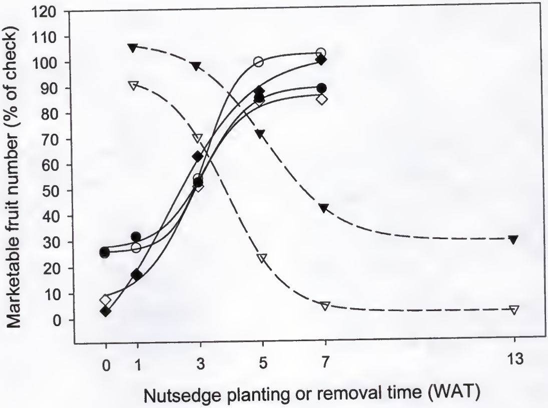


Fig. B-2. Season and nutsedge planting (—) or removal (----) time (weeks after pepper transplanting; WAT) effects on large bell pepper fruit number as percent of that obtained with pepper grown weed-free. Data within means (shown) were regressed with sigmoidal models. Equations for the plant back study in spring (●) and fall (○), respectively, were $Y = 27.6 + 64.8/(1 + e^{(-(X - 3.3)/0.52))})$ and $Y = -7.9 + 98.9/(1 + e^{(-(X - 2.5)/1.10))})$. Equations for the time of removal study in spring (■) and fall (□), respectively, were $Y = 30.1 + 73.4/(1 + e^{(-(X - 5.0)/-0.80))})$ and $Y = 1.24 + 96.6/(1 + e^{(-(X - 3.3)/-0.60))})$. Models was significant at $P \leq 0.001$.



● PB spring trial A: $\{Y = 27.1 + 62.2/(1 + e^{(-(X-3.25)/0.725)})\}$; $r^2 = 0.87$

○ PB spring trial B: $\{Y = 25.8 + 76.4/(1 + e^{(-(X-3.30)/0.552)})\}$; $r^2 = 0.88$

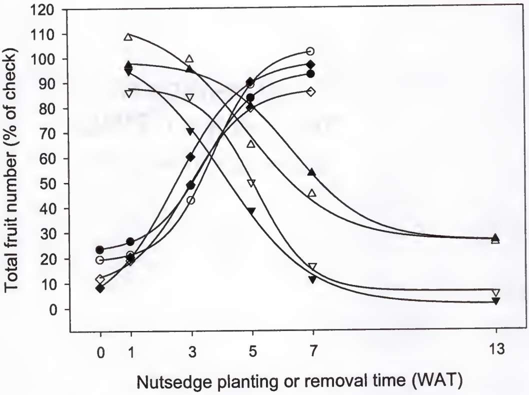
◆ PB fall trial A: $\{Y = -17.6 + 119.1/(1 + e^{(-(X-2.10)/1.33)})\}$; $r^2 = 0.86$

◇ PB fall trial B: $\{Y = 6.71 + 79.6/(1+ e^{(-(X-2.77)/0.810)})\}$; $r^2 = 0.98$

▼ TR spring: $\{Y = 28.9 + 78.9/(1 + e^{(-(X - 5.19)/-1.12)})\}$; $r^2 = 0.81$

▽ TR fall: $\{Y = 1.65 + 92.8/(1 + e^{(-(X - 3.93)/-0.90)})\}$; $r^2 = 0.90$

Fig. B-3. Season and nutsedge planting (PB; —) or removal (TR; ----) time (weeks after pepper transplanting; WAT) effects on marketable bell pepper fruit number as percent of that obtained with pepper grown weed-free. Data within means (shown) were regressed with sigmoidal models that were significant at $P \leq 0.001$.



● PB spring trial A: $\{Y = 22.3 + 71.8/(1 + e^{(-(X - 3.47)/0.873)})\}$; $r^2 = 0.94$

○ PB spring trial B: $\{Y = 18.6 + 84.8/(1 + e^{(-(X - 3.73)/0.800)})\}$; $r^2 = 0.96$

◆ PB fall trial A: $\{Y = -1.06 + 99.7/(1 + e^{(-(X - 2.47)/1.11)})\}$; $r^2 = 0.90$

◇ PB fall trial B: $\{Y = 8.86 + 78.4/(1 + e^{(-(X - 2.93)/0.964)})\}$; $r^2 = 0.96$

▲ TR spring trial A: $\{Y = 26.3 + 72.4/(1 + e^{(-(X - 6.36)/-1.22)})\}$; $r^2 = 0.87$

△ TR spring trial B: $\{Y = 26.1 + 89.5/(1 + e^{(-(X - 4.83)/-1.44)})\}$; $r^2 = 0.89$

▼ TR fall trial A: $\{Y = 1.14 + 104.0/(1 + e^{(-(X - 4.07)/ -1.43)})\}$; $r^2 = 0.95$

▽ TR fall trial B: $\{Y = 6.36 + 81.9/(1 + e^{(-(X - 5.15)/-0.8625)})\}$; $r^2 = 0.92$

Fig. B-4. Interaction of year, season, and nutsedge planting (PB; —) or removal (TR; ----) time (weeks after pepper transplanting; WAT) on total bell pepper fruit number as percent of that obtained with pepper grown weed-free. Data within means (shown) were regressed with sigmoidal models that were significant at $P \leq 0.001$.

Tuber Distance Studies

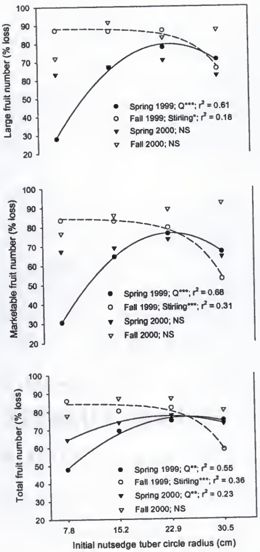


Fig. B-5. Year, season, and initial yellow nutsedge tuber circle radius effects on loss of large (A), marketable (B), and total (C) pepper fruit number relative to yield from pepper grown weed-free. Data within means (shown) were regressed with a quadratic (Q) or best-fit nonlinear (Stirling) model. Effects were nonsignificant (NS) or significant at $P \leq 0.01$ (**) or 0.001 (***). Equations for significant effects were A.) ●: $\{Y = -30.9 + 9.3(X) - 0.2(X^2)\}$; ○: $\{Y = 88.2 - 0.0032 \times (e^{(0.24(X)}-1)/0.24)\}$. B.) ●: $\{Y = 24.8 + 8.7(X) - 0.19(X^2)\}$; ○: $\{Y = 84.5 - 0.010 \times (e^{(0.21(X)}-1)/0.21)\}$. C.) ●: $\{Y = 18.6 + 4.6(X) - 0.09(X^2)\}$; ○: $\{Y = 84.3 - 0.0052 \times (e^{(0.23(X)}-1)/0.23)\}$; ▼: $\{Y = 47.4 + 2.7(X) - 0.06(X^2)\}$.

APPENDIX C
TOTAL KJELDAHL N ANALYSIS

Wet Ash Digestion Procedures

1. Weighed 100 mg (wt tolerance of 0.099 to 0.101 g) sample of previously ground plant tissue and poured it into a 50 ml PYREX digestion tube.

2. Scooped 2 g of Pope Kjeldahl (10 g K_2SO_4: 3 g $CuSO_4$; Pope Kjeldahl Mixture, Inc. P.O. Box 903 Dallas, Texas 75221 or 2618 Main Dallas, Texas 75226) and pipetted 2.5 ml H_2SO_4 into each tube.

3. Placed tubes on digestion block and placed a glass funnel on each tube. Turned the block on at 380 °C and set timer to cook samples for approximately 8 hours. After the block had cooled, the tubes were removed and placed on racks.

4. Rinsed the inner sides of each tube with 20 ml of deionized H_2O, mixed with a Vortex Genie until gel was dissolved, and filled each tube to the 50-ml mark with deionized H_2O.

5. Filtered diluted sample in each tube with P8 (Whatman) filter paper placed in a glass funnel, allowing leachate to drain into a previously marked 20-ml scintillation vial placed under the glass funnel. Vials were filled to the shoulder and stored in the refrigerator until analyzed for TKN using a Rapid Flow Analyzer via colorimetry.

Dilution factor calculation

Parmeters: 100 mg sample/50 ml total volume

Desired units to express on a % dry wt (g) basis:

100 mg = 0.1 g
0.1 g sample/ 50 ml total volume = a dilution factor of 1/500

TKN from lab expressed as parts per million (ppm): 500/1,000,000*100 = 0.05%

Therefore, each TKN value (in ppm) was multiplied by 0.05 to obtain % N of tissue dry wt.

APPENDIX D
SAMPLE CALCULATIONS

Dowel Spacing on Boards in Additive Studies

Procedure for Building Each Tuber Planting Board

1. Cut a plywood board to one third or half the length of a plot.
2. Drew lines on board to form a pattern of squares.
3. Attached a dowel via a wood-screw at each point where grid lines intersected.

Dimensions of Squares Drawn on Board in:

Spring 1999 additive study:

Maximum tuber (dowel) density = 120 tubers/m^2

Area as cm^2 occupied by one tuber = $(10{,}000\ cm^2/m^2)/120 = 83.3\ cm^2$

Square root of 83.3 = 9.1; therefore, squares were 9.1 cm X 9.1 cm

Fall 1999 and in spring and fall 2000 additive studies:

Maximum tuber (dowel) density = 90 tubers/m^2

Area as cm^2 occupied by one tuber = $(10{,}000\ cm^2/m^2)/90 = 111.1\ cm^2$

Square root of 111.1 = 10.5; therefore, squares were 10.5 cm X 10.5 cm

Spring and fall 2000 critical period studies:

Maximum tuber (dowel) density = 45 tubers/m^2

Area as cm^2 occupied by one tuber = $(10{,}000\ cm^2/m^2)/45 = 222.2\ cm^2$

Square root of 222.2 = 14.9; therefore, squares were 14.9 cm X 14.9 cm

Tuber Density in Nutsedge Circles

Circle Radii

In centimeters: 0, 7.6, 15.2, 22.9, 30.5 cm

In meters: 0, 0.076, 0.152, 0.229, 0.305 m

Circle Areas

Formula = pi X square of radius

Areas = 0.018, 0.073, 0.164, and 0.292 m^2 pi X square of radius, respectively, with circle radii of 0.076, 0.152, 0.229, and 0.305 m.

Tuber Densities

Formula = Tuber number/area

Densities

With tubers spaced 5 cm: 500, 260, 170, and 130 tubers$\cdot m^{-2}$, respectively, with circle radii of 0.076, 0.152, 0.229, and 0.305 m.

With tubers spaced 10 cm: 217, 123, 85, and 65 tubers$\cdot m^{-2}$, respectively, with circle radii of 0.076, 0.152, 0.229, and 0.305 m.

Fertilizer Calculations

Desired Amounts of N, P_2O_5, and K_2O Needed Per Hectare:

Total N, P_2O_5, and K_2O= 224, 84, and 224 kg, respectively

Preplant-applied N, P_2O_5, and K_2O = 84 kg for each nutrient

Drip-applied N and K_2O:

N and K_2O = 224 kg total - 84 kg preplant = 140 kg total drip
Therefore, 14 kg of N and K_2O needed for each of 10 weekly fertigations.

Amount of Preplant Fertilizer Needed:

Analysis of fertilizer: 10% N, 10% P_2O_5, 10% K_2O

Amount of fertilizer needed per hectare:
84 kg nutrient X (100 kg fertilizer/10 kg nutrient) = 840 kg 10-10-10 fertilizer

Number of hectares:
76.2 m row length X 1.22 m bed width X 12 rows = 1114.8 m^2
1114.8 m^2/10,000 m^2/hectare = 0.111 hectare

Amount of fertilizer needed for field (calculation shown for one field):
840 kg 10-10-10 fertilizer/ha X 0.111 ha = 93.5 kg 10-10-10 fertilizer

Amount of Drip-Applied NH_4NO_3 and KCl Needed Each Week:

Analysis of fertilizer: 34% N in NH_4NO_3; 60% K_2O in KCl

Amount of fertilizer needed:

NH_4NO_3: 14 kg N X (100 kg fertilizer/34 kg N) = 41.2 kg fertilizer
41.2 kg fertilizer/ha X 0.111 ha/field = 4.6 kg fertilizer

KCl: 14 kg K_2O X (100 kg fertilizer/60 kg K_2O) =
23.3 kg fertilizer/ha X 0.111 ha/field = 2.6 kg fertilizer

N Uptake by Pepper Plant Tissue

Parameters:

Plant spacing in double rows in additive experiments: 0.2286 and 0.3048 m

Plant spacing in single rows in circle studies: 0.4572 m

Bed width (center to center) in all experiments: 1.2192 m

Land area per pepper plant:

For plants spaced 0.2286 m: (0.2286 m X 1.2192 m)/2 = 0.139 m^2
For plants spaced 0.3048 m: (0.3048 m X 1.2192 m)/2 = 0.186 m^2
For plants spaced 0.4572 m: 0.4572 m X 1.2192 m = 0.5574 m^2

Dry weight of sampled tissue: 10 g

N concentration in sampled tissue: 4% dry weight

Calculations:

To obtain g N in tissue: 10 g X 0.04 = 0.4 g N/plant

To obtain g N taken up per m^2:

With plant spaced 0.2286 m: (0.4 g N/plant)/0.139 m^2 = 2.9 g/m^2
With plant spaced 0.3048 m: (0.4 g N/plant)/0.186 m^2 = 2.2 g/m^2
With plant spaced 0.5574 m: (0.4 g N/plant)/0.5574 m^2 = 0.7 g/m^2

To obtain kg N taken up per ha:

With plant spaced 0.2286 m: (2.9 g/m^2 X 10,000 m^2/ha)/1000 = 29 kg/ha

With plant spaced 0.3048 m: (2.2 g/m^2 X 10,000 m^2/ha)/1000 = 22 kg/ha

With plant spaced 0.5574 m: (0.7 g/m^2 X 10,000 m^2/ha)/1000 = 7 kg/ha

Uptake of N by Nutsedge in Spring 1999 Additive Study

Parameters:

Shoot number sampled in a 0.1 m^2 area: 100

Number of shoots sampled: 28

Dry weight of sampled shoots: 10 g

N concentration of sampled shoots: 2%

Calculations:

To determine g N taken up per m^2:

Calculate shoot number/m^2: 100 shoots/0.1 m^2 = 1000 shoots/m^2

Calculate N uptake by one shoot:

10 g/28 shoots = 0.36 g/shoot

0.36 g X 0.02 = 0.007 g N/shoot

Multiply g N/shoot by the number of shoots in a m^2:

0.007 g N/shoot X (1000 shoots/m^2) = 7.1 g N/m^2

Convert g N/m^2 to kg N/ha:

Determine kg N/m^2: (7.1 g N/m^2)/1000 = 0.0071 kg N/m^2

Convert kg N/m^2 to kg N/ha:

(0.0071 kg N/m^2) X (10,000 m^2/ha) = 71 kg N/ha

Uptake of N by Nutsedge in Additive Studies in 2000

Parameters:

Dry weight of sampled shoots in a 0.1 m^2 area: 100 g

N concentration of sampled shoots: 2%

Calculations:

Determine g N taken up per m^2:

Calculate shoot dry weight/m^2: 100 g/0.1 m^2 = 1000 g/m^2

Calculate N uptake/m^2: 1000 g/m^2 X 0.02 = 20 g N/m^2

Convert g N/m^2 to kg N/ha:

Determine kg N/m^2: (20 g N/m^2)/1000 = 0.02 kg N/m^2

Convert kg N/m^2 to kg N/ha:

(0.02 kg N/m^2) X (10,000 m^2/ha) = 200 kg N/ha

Uptake of N in the Tuber Distance Studies in 1999

Parameters:

Circumference of 15.2 cm-radius circle: 95.8 cm

Number of shoots in a 25 cm section of above circumference: 100

Number of shoots sampled in the 25 cm section: 40

Land area occupied by one pepper plant: 0.5574 m^2

Dry weight and N concentration of sampled shoots: 10 g and 2%, respectively

Calculation steps:

Determine shoot number around one pepper plant:

Calculate no. of 25-cm sections in a circle: 95.8 cm/25 cm = 3.8 sections

Shoot no./plant = (100 shoots/section) X 3.8 sections = 380

Determine kg N taken up by nutsedge shoots around one pepper plant:

Calculate dry wt/shoot: 10 g/40 shoots = 0.25 g/shoot

Calculate shoot dry wt/circle:

(0.25 g/shoot) X (380 shoots/circle) = 95 g/circle

Kg N/pepper plant = (95 g dry wt/circle X 0.02)/1000 = 0.0019

Determine kg nutsedge shoot N uptake per ha:

Calculate number of pepper plants per ha:
(plant/0.5574 m^2) X (10,0000 m^2/ha) = 17,940 plants/ha

Calculate kg N uptake/ha:

(0.0019 kg N/plant) X (17,940 plants/ha) = 34 kg N/ha

Uptake of N in the Tuber Distance Studies in 2000

Parameters:

Circumference of 15.2 cm-radius circle: 95.8 cm

Dry weight of shoots in a 25 cm section of above circumference: 100 g

Land area occupied by one pepper plant: 0.5574 m^2

N concentration of sampled shoots: 10 g and 2%, respectively

Calculation steps:

Determine kg N taken up by nutsedge shoots around one pepper plant:

Calculate no. of 25-cm sections in a circle: 95.8 cm/25 cm = 3.8 sections

Calculate shoot dry wt/circle: 100 g/section X 3.8 sections = 380 g/circle

Kg N/pepper plant = (380 g dry wt/circle X 0.02)/1000 = 0.0076

Determine kg nutsedge shoot N uptake per ha:

Calculate number of pepper plants per ha:

(plant/0.5574 m^2) X (10,0000 m^2/ha) = 17,940 plants/ha

Calculate kg N uptake/ha:

(0.0076 kg N/plant) X (17,940 plants/ha) = 136 kg N/ha

Amount of 1,3-D + Pic and Metam-Na in Pans

Feet^2/pan: length X width = 1.17 ft X 0.79 ft = 0.9236 ft^2

1,3-D + Pic: 3785 ml/gal X 35 gal/acre X acre/43560 ft^2 X 0.9236 ft^2/pot = 2.8 ml/pan

Vapam: 3785 ml/gal X 75 gal/acre X acre/43560 ft^2 X 0.9236 ft^2/pot = 6.0 ml/pan

Outlier #1: 3785 ml/gal X 37.5 gal/acre X acre/43560 ft^2 X 0.92 ft^2/pot = 3.0 ml/pan
Outlier #2: 3785 ml/gal X 150 gal/acre X acre/43560 ft^2 X 0.92 ft^2/pot = 12.0 ml/pan

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BIOGRAPHICAL SKETCH

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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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